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An Approach to Water Resources Evaluation of Non-Point Silvicultural Sources (A Procedural Handbook)

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Washington, DC

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An Approach to Water Resources Evaluation of Non-Point Silvicultural Sources (A Procedural Handbook)

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This handbook provides an analysis methodology that can be used to describe and evaluate changes to the water resource resulting from non-point silvicultural activities. It covers only the pollutant generation and transport processes and does not consider the economic, social, and political aspects of pollution control.

This state-of-the-art approach for analysis and prediction of pollution from non point silvicultural activities is a rational estimation procedure that is most useful in making comparative analyses of management alternatives. These comparisons are used in selecting preventive and mitigative controls and require site-specific data for the analysis.

This handbook also provides quantitative techniques for estimating potential changes in streamflow, surface erosion, soil mass movement, total potential sediment discharge, and temperature. Qualitative discussions of the impacts of silvicultural activities on dissolved oxygen, organic matter, nutrients, and introduced chemicals are included.

A control section provides a list of control practices that have been used effectively and a methodology for selecting mixtures of these controls for the prevention and mitigation of water resource impacts. Such mixtures are the technical basis for formulating Best Management Practices.

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by

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This report has been reviewed by the Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, Georgia, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

SPECIAL DEDICATION
DAVID A. FALLETTI

Dave Falletti recently met an untimely death while the manuscript was being prepared. He put in many hours of work and much dedication to the project, taking it through many complex obstacles. Those who have carried on this work have been guided by Dave's inspiration. The final document represents many of his ideas which we hope will be put into practice.

FOREWORD

Our Nation's forests are major sources of valuable resources including water supplies, wildlife habitats, recreational areas, and timber products. As pressures for these resources increase, the need to integrate resource management practices with techniques for controlling soil erosion and preventing the discharge of pollutants into the Nation's waters becomes more important. To further this integration, the Forest Service, U.S. Department of Agriculture, and the Athens Environmental Research Laboratory, U.S. Environmental Protection Agency, established a research project to develop methods for identifying and assessing alternative technical solutions to pollution problems associated with specific silvicultural activities.

This handbook addresses the technical aspects of non-point source water pollution related to silviculture as expressed in the Federal Water Pollution Control Act Amendments of 1972 and the Clean Water Act of 1977. It was designed to aid environmental managers in developing water quality management plans, strategies, and implementation programs and should be used in conjunction with local expertise and information on economic, social, and institutional aspects of silvicultural activities.

David W. Duttweiler
Director
Environmental Research Laboratory
Athens, Georgia

ABSTRACT

This handbook provides an analysis methodology that can be used to describe and evaluate changes to the water resource resulting from non-point silvicultural activities. It covers only the pollutant generation and transport processes and does not consider the economic, social and political aspects of pollution control.

This state-of-the-art approach for analysis and prediction of pollution from non-point silvicultural activities is a rational estimation procedure that is useful in making comparative analyses of management alternatives. These comparisons are used in selecting preventive and mitigative controls and require site-specific data for the analysis.

This handbook also provides quantitative techniques for estimating potential changes in streamflow, surface erosion, soil mass movement, total potential sediment discharge, and temperature. Qualitative discussions of the impacts of silvicultural activities on dissolved oxygen, organic matter, nutrients, and introduced chemicals are included.

A control section provides a list of control practices that have been used effectively and a methodology for selecting mixtures of these controls for the prevention and mitigation of water resource impacts. Such mixtures are the technical basis for formulating Best Management Practices.

This report was submitted in fulfillment of Interagency Agreement Number EPA-IAG-D6-0660 by the Forest Service, U.S. Department of Agriculture, under an agreement with the U.S. Environmental Protection Agency. This report covers the period December 1, 1976, to December 1, 1979, and work was completed as of December 1, 1979.

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The "Control Opportunities" chapter was the collective work of many individuals. A committee chaired by Wayne Patton prepared the material. Committee members were George Dissmeyer, Joe Gorsh, Lee Cromley, Al Dahlgreen, Clay Smith, Doug Roy, Bill Beaufait, and Leland Fansher.

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Special thanks go to all the editing, graphics, clerical staff, and detailers for their work on both the draft and final manuscripts. Coordinating editors were Marianne Rieux (draft manuscript) and Janet Sheppard (final manuscript). Also editing were Lynnea Erickson, Charlotte Yarrington, Pete Baez, and Vivian Lollis. Joyce Reid was primary illustrator assisted by Marnie Benson. Typing was shared by Edie DeWeese, Lorraine Jehu, Anne Peterson, Annie Hanson, and Jo Laaksonen. Marilyn Whitfield, assisted by Eva Erickson, coordinated the office throughout work on the manuscript.

CONVERSION FACTORS FOR U.S. AND METRIC UNITS

To convert column 1 into column 2, multiply by	Column 1	Column 2	To convert column 2 into column 1, multiply by
	LENGTH		
0.621	kilometer, km	mile, mi	1.609
1.094	meter, m	yard, yd	0.914
0.394	centimeter, cm	inch, in	2.54
	AREA		
0.386	kilometer^2, km^2	mile^2, mi^2	2.590
247.1	kilometer^2, km^2	acre, acre	0.00405
2.471	hectare, ha	acre, acre	0.405
	VOLUME		
0.00003531	centimeter^3, cm^3	foot^3, ft^3	28316.8
0.00973	meter^3, m^3	acre-inch	102.8
1.057	liter	quart (liquid), qt	0.946
1.3079	meter^3, m^3	cubic yard, yd^3	0.7646
	MASS		
1.102	ton (metric)	ton (U.S.)	0.9074
2.205	kilogram, kg	pound, lb	0.454
0.035	gram, g	ounce (avdp), oz	28.35
	PRESSURE		
14.50	bar	lb/inch^2, psi	0.06895
0.9869	bar	atmosphere, atm	1.013
0.9678	kg (weight)/cm^2	atmosphere, atm	1.033
14.22	kg (weight)/cm^2	lb/inch^2, psi	0.07031
	YIELD OR RATE		
0.446	ton (metric)/hectare	ton (U.S.)/acre	2.240
0.892	kg/ha	lb/acre	1.12
	TEMPERATURE		
	Celsius	Fahrenheit	
	−17.8C	0F	
$\left(\frac{9}{5}\ ^\circ\mathrm{C}\right)+32$	0C	32F	$\frac{5}{9}\ (^\circ\mathrm{F}-32)$
	20C	68F	
	100C	212F	
	DENSITY		
62.43	gm/cm^3	lb/ft^3	0.016
	WATER MEASUREMENT		
8.108	hectare-meters, ha-m	acre-feet	0.1233
97.29	hectare-meters, ha-m	acre-inches	0.01028
0.00973	meters^3, m^3	acre-inches	102.8
0.00981	meters^3/hour, m^3/hour	feet^3/sec	101.94

INTRODUCTION

The Federal Water Pollution Control Act Amendments of 1972, commonly referred to as Public Law 92-500, established definite goals regarding the restoration and maintenance of the physical, chemical, and biological integrity of the Nation's waters. The Act requires that water quality management planning, carried out under Section 208 of the Act, include a process that identifies non-point sources of water pollution and that establishes methods to control those sources to the extent feasible. Non-point sources associated with silviculture and related runoff are among several sources specifically mentioned in the Act as areas to be addressed during 208 planning and implementation.

The purpose of this technical handbook is to provide a systematic, procedural, and analytical methodology for identifying and assessing alternative technical solutions to existing or potential non-point source problems associated with site-specific silvicultural activities. While the specific analytical methods presented are not the only methods available, they were carefully chosen according to the capabilities of the science and the present state-of-the art.

Non-point sources of pollution result from natural causes, human actions, and the interactions between natural events and conditions associated with human use of the land and its resources. To control these sources, the United States Environmental Protection Agency (EPA) has adopted, through Federal Regulation, the concept of Best Management Practices. As defined by EPA,

> Best Management Practices (BMP) means a practice or combination of practices that are determined by a state (or designated area-wide planning agency) after problem assessment, examination of alternative practices, and appropriate public participation to be the most effective, practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by non-point sources to a level compatible with water quality goals.

This handbook deals specifically with the concern and requirement for control of non-point sources of water pollution related to silvicultural activities as expressed in the Federal Water Pollution Control Act Amendments of 1972 and the Clean Water Act of 1977. The handbook covers only the technical aspects of non-point source water pollution control; it does not address the economic, social, and institutional aspects that are also an important part of the Best Management Practices identification process. The economic considerations are described in "Silvicultural Activities and Non-Point Pollution Abatement: A Cost-Effectiveness Analysis Procedure" (USDA FS 1978). The social and institutional considerations are manifested through public involvement during environmental assessment review processes.

DEFINITION OF EXISTING WATER QUALITY AND WATER QUALITY OBJECTIVES

A prerequisite for use of this technical evaluation procedure is the identification of existing water quality and water quality objectives as quantifiable numerical expressions. This type of objective provides a base against which the impacts of the proposed silvicultural activities can be compared so the degree of additional control measures necessary can be identified.

In defining water quality objectives against which analysis results will be compared, it must be noted that the present state-of-the-art is, at best, a rational estimation procedure. Comparative analysis will often fall short of predicting absolute values.

APPLICATION OF THE PROCEDURE

Silvicultural activities to which the described procedures apply include timber harvesting, transportation systems, and various cultural practices such as site preparation and timber stand improvement. These silvicultural activities are discussed in relationship to the principal potential water pollutants that may be generated and transported from the site. Such pollutants include inorganic sediment, nutrients (primarily nitrogen and phosphorus), heat, organic debris and introduced chemicals such as pesticides and fertilizers.

Technical procedures and methods suggested in this handbook fit within the overall process for non-point source control as identified in EPA's "Non-Point Source Control Guidance Silviculture" document (Singer and Maloney 1977). The subjects covered in this handbook are those within the shaded area shown in the process outline, figure 1. Included are the specific analysis methods required to meet steps 1 through 7 of the non-point control process. The methodology also provides a simulation technique that can be used to estimate the past and present condition of receiving waters (step 3) when such information is not available.

The procedure gives proper recognition to space and time variations occurring in natural environments, to the pollution generation processes involved, and to defined water quality objectives. Thus, it permits evaluation of water quality management options at a level compatible with other resource evaluations. It also permits comparison of the effects of proposed management alternatives on water quality in different watersheds and on different areas within a specific watershed, given the same data base.

Application of the technical methodology generally requires a basic knowledge of hydrology plus a working knowledge of forestry, soil science, and engineering principles as they are applied in a natural environment. For all practical purposes, analysis and prediction of non-point sources of water pollution is a rational estimation procedure that is useful in comparative analysis of alternatives. Therefore, it is necessary for informed professionals to use local experience in applying the analysis techniques.

Although primarily a guide for the technical specialist, the handbook is also designed for water quality management planners and other land managers. The flow charts in the "Introduction," "Procedural Summary," and "Control Opportunities" chapters guide these managers in defining technical assessments needed. The analytical procedures and references in the technical chapters guide technical specialists or consultants in making those assessments. The step-by-step illustrations in the "Control Opportunities" chapter guide project designers and managers in identifying appropriate practices for the particular activity and site conditions.

CHARACTERIZATION OF THE SITE

Because the character of a site largely determines the non-point sources that might be encountered and the effectiveness of specific control measures, good site characterization data is essential.

Soil survey reports, stream survey reports, and geologic, climatic, topographic, and vegetation maps with accompanying descriptive materials all provide input for development of water quality plans and other environmental assessments. The level of detail in these documents should be compatible with the degree of reliability expected from the analysis (recognizing the sensitivity as well as the strengths and weaknesses of the analytical procedure in terms of data input.)

In order to evaluate non-point sources on specific sites or projects, the level of information must be compatible with the map resolution used to identify the first-, second-, or third-order drainage basins as described by Strahler (1957). The handbook analysis procedure is applicable only to these headwater areas (third-order basins or smaller).

A larger basin may be characterized from selected third-order drainages within that basin through data analysis and extrapolation based upon the similarities in site and management activities. These evaluations may be useful in identifying general types of practices which may represent BMP and in analyzing responses for specific silvicultural activities basin-wide. However, the site-specific analysis is the only option that considers site and activity variability and the identification of a site-specific BMP.

An environmental setting is a continuum which includes the hydrologic cycle, the nutrient cycle, and the erosion/sediment processes. The nature of the non-point process is such that the potential pollutant must be traced as thoroughly as possible

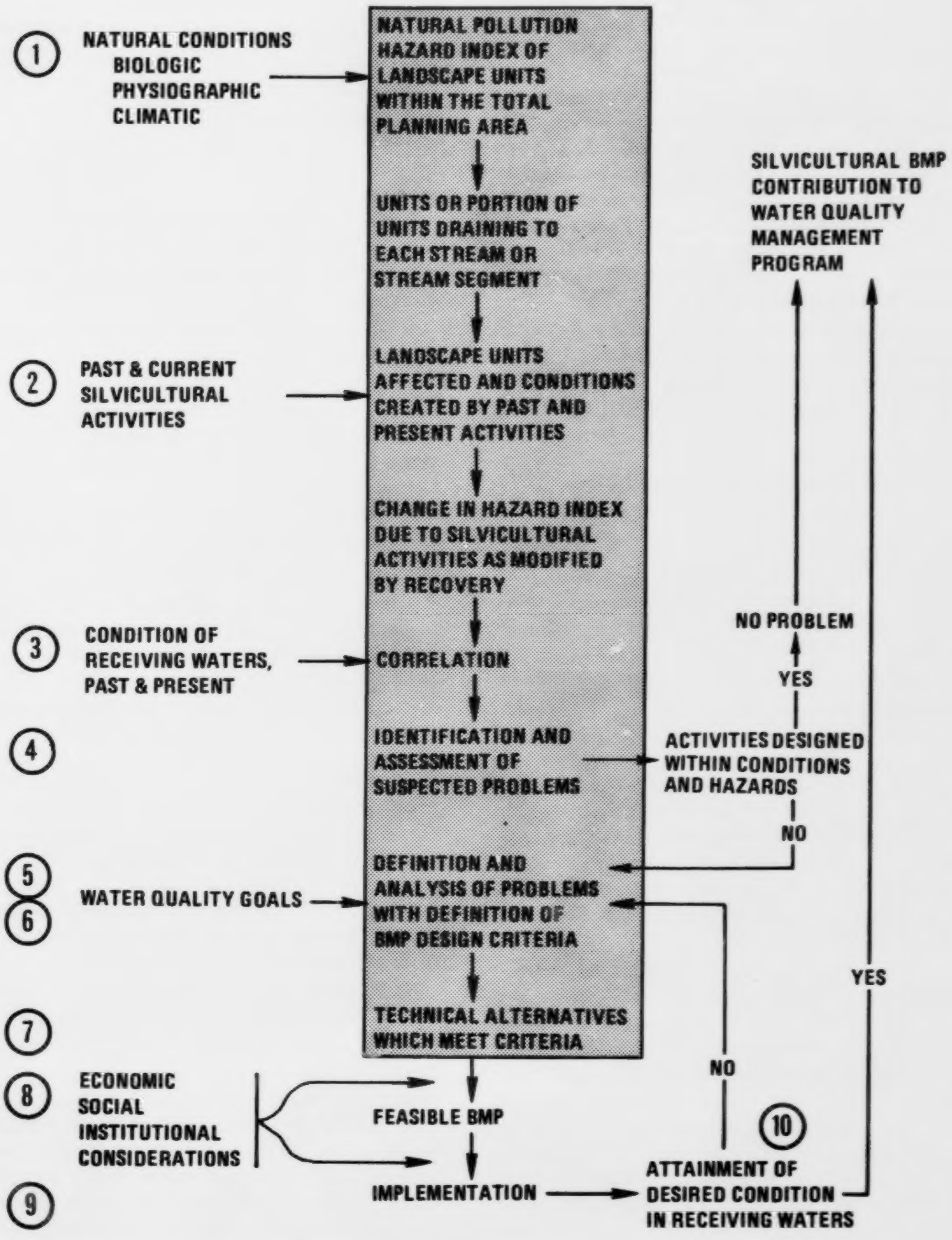
1
NATURAL CONDITIONS
BIOLOGIC
PHYSIOGRAPHIC
CLIMATIC
NATURAL POLLUTION HAZARD INDEX OF LANDSCAPE UNITS WITHIN THE TOTAL PLANNING AREA
UNITS OR PORTION OF UNITS DRAINING TO EACH STREAM OR STREAM SEGMENT
2
PAST & CURRENT SILVICULTURAL ACTIVITIES
LANDSCAPE UNITS AFFECTED AND CONDITIONS CREATED BY PAST AND PRESENT ACTIVITIES
CHANGE IN HAZARD INDEX DUE TO SILVICULTURAL ACTIVITIES AS MODIFIED BY RECOVERY
3
CONDITION OF RECEIVING WATERS, PAST & PRESENT
CORRELATION
4
IDENTIFICATION AND ASSESSMENT OF SUSPECTED PROBLEMS
ACTIVITIES DESIGNED WITHIN CONDITIONS AND HAZARDS
YES
NO PROBLEM
SILVICULTURAL BMP CONTRIBUTION TO WATER QUALITY MANAGEMENT PROGRAM
NO
5
6
WATER QUALITY GOALS
DEFINITION AND ANALYSIS OF PROBLEMS WITH DEFINITION OF BMP DESIGN CRITERIA
7
TECHNICAL ALTERNATIVES WHICH MEET CRITERIA
8
ECONOMIC
SOCIAL
INSTITUTIONAL
CONSIDERATIONS
FEASIBLE BMP
9
IMPLEMENTATION
10
ATTAINMENT OF DESIRED CONDITION IN RECEIVING WATERS
NO
YES

Figure 1.—Non-point pollution control process for silviculture (Singer and Maloney 1977).

through the entire system; therefore, all major environmental factors significantly affecting its generation and transport (into the receiving waters) must be recognized. Then these factors must be related to the physical and biological processes that govern the pollutant's ultimate disposition. This process is critical in determining controls for non-point sources caused by silvicultural activities because most water quality constituents identified as pollutants also occur naturally within the system. The analysis methodology is structured to differentiate natural pollution sources from those which may have resulted from human activities.

This document does not discuss all potential pollutants. It does describe, in a procedural manner, those potential pollutants that have been identified as being most important on a national basis.

General Procedural Description

The handbook procedure addresses the examination of the factors associated with generation and transport of pollutants; it discusses identification, in comparative, numerical, or qualitative terms, of the changes in pollutant output expected to follow particular silvicultural activities on a specific site.

The techniques suggested for comparing existing water quality with the water quality changes expected from proposed silvicultural activity provide a rational approach for dealing with the following facts: (1) day-to-day variations in water quality in undisturbed forest watersheds are substantial, particularly during the periods of changing flows; and (2) fluctuations in undisturbed systems may be as great as those in apparently similar, but disturbed, systems.

The procedure evaluates proposed silvicultural plans to identify expected changes in water quality and to determine the type and degree of control needed, if any, to meet water quality objectives. The evaluation process continues until: (1) a combination of preventive and mitigative controls that meets the objectives has been identified, or (2) an acceptable land use alternative, which meets the objectives, has been determined. Mitigative controls may be necessary to correct existing non-point sources before any new activities can be made technically acceptable.

The following requirements must be met before applying the analysis procedure presented in this handbook:

1. Water quality objectives should be identified and described with current information suitable for comparative analyses.
2. The pollutants should be identified in terms of units, time, and space; and those terms should be compatible with the terms of the analysis procedure.
3. Specific information as required for the analysis should be available to evaluate the silvicultural impacts onsite on a third-order basin or smaller.
4. The causes of non-point sources should be recognizable.
5. Water quality existing prior to initiation of silvicultural activities should be measured or estimated with a reasonable degree of reliability through analysis of other appropriate types of information.
6. Water quality after silvicultural activities should be estimated using the same approach applied to define existing conditions.

This document includes an introduction; a procedural summary; a control opportunities section; five technical chapters with quantitative discussions of hydrology, surface erosion, soil mass movement, total potential sediment, and temperature; an example demonstrating the quantitative procedures; three technical chapters with qualitative discussions of nutrients, dissolved oxygen and organic matter, and introduced chemicals; and a glossary of terms. The procedural summary provides a general overview and a simplified analysis methodology for each subsequent chapter showing the general processes and their relationships. The control opportunities and technical chapters present a detailed discussion of the procedures involved and the interrelationships between processes.

The general procedure and interrelationships between the control opportunities and the technical chapters, both quantitative and qualitative, are presented in the flow diagram, figure 2. The diagram depicts the iterative process that may be required if the proposed silvicultural activity does not meet water resource goals. During this process, the control opportunities are evaluated and the silvicultural activity revised as needed.

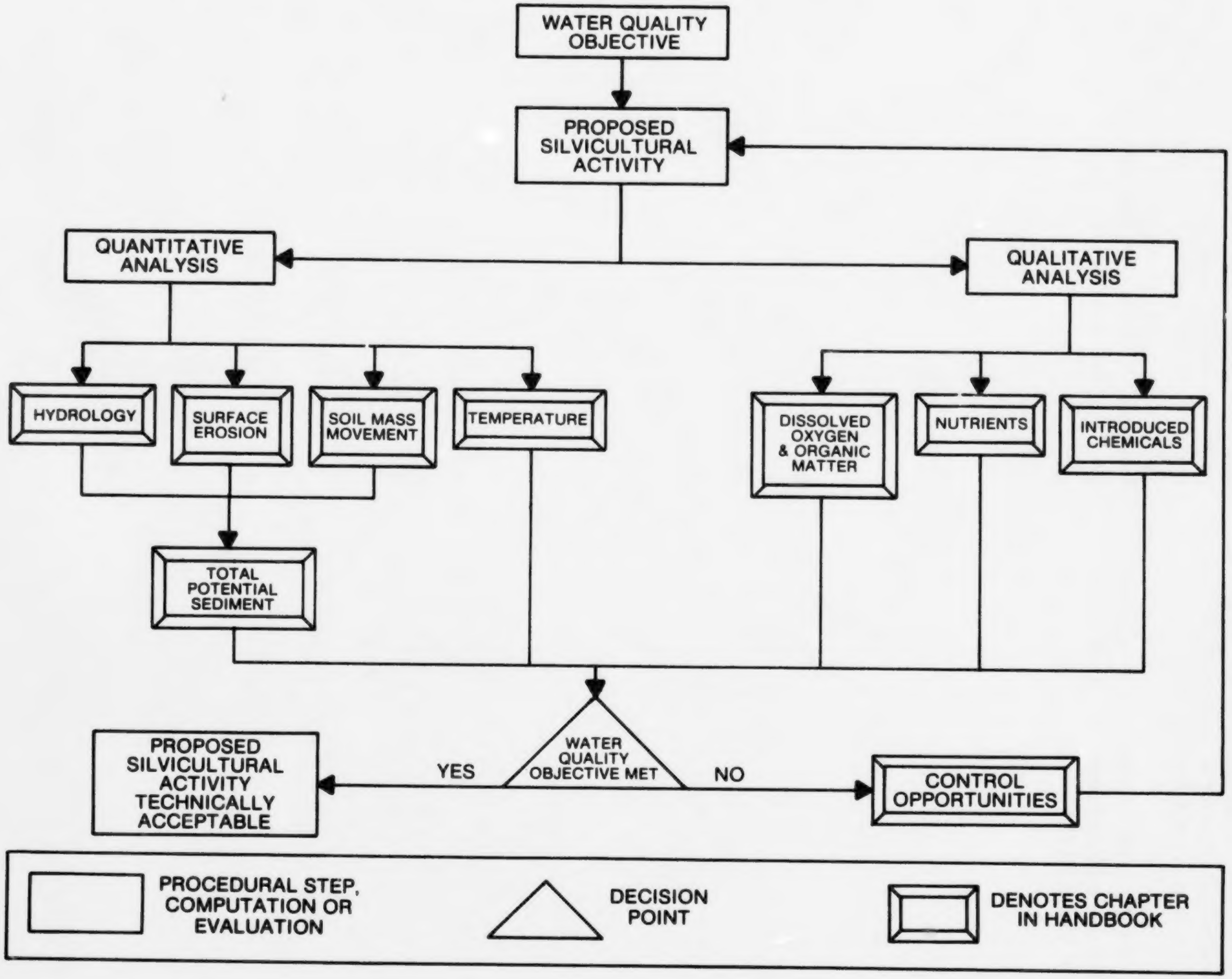
WATER QUALITY OBJECTIVE
PROPOSED SILVICULTURAL ACTIVITY
QUANTITATIVE ANALYSIS
QUALITATIVE ANALYSIS
HYDROLOGY
SURFACE EROSION
SOIL MASS MOVEMENT
TEMPERATURE
TOTAL POTENTIAL SEDIMENT
DISSOLVED OXYGEN & ORGANIC MATTER
NUTRIENTS
INTRODUCED CHEMICALS
WATER QUALITY OBJECTIVE MET
YES
NO
PROPOSED SILVICULTURAL ACTIVITY TECHNICALLY ACCEPTABLE
CONTROL OPPORTUNITIES
PROCEDURAL STEP, COMPUTATION OR EVALUATION
DECISION POINT
DENOTES CHAPTER IN HANDBOOK

Figure 2.—Interrelationships between the quantitative, qualitative, and control chapters and their application to a proposed silvicultural activity.

LITERATURE CITED

Singer, J. R. and R. C. Maloney. 1977. Nonpoint source control guidance for silviculture. U.S. Environ. Prot. Agency, Washington, D.C.

Strahler, A. N. 1957. Quantitative analysis of watershed geomorphology. Trans. Am. Geophys. Union 38:913-920.

U.S. Department of Agriculture, Forest Service. 1978. Silvicultural activities and non-point pollution abatement: a cost-effectiveness analysis procedure. Prepared under Interagency Agreement No. EPA-IAG-D6-0660 with the Environ. Prot. Agency, Athens, Ga.

Chapter I

PROCEDURAL SUMMARY

This chapter was prepared by a committee composed of the individual coordinators for chapters II to XI.

Leif E. Siverts

Chairman

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INTRODUCTION

This chapter summarizes all procedures presented in the handbook. It is meant to provide an overview of the analyses, clarify usage of techniques and information, and indicate the interrelations between the various chapters. Procedural summaries appear for the quantitative chapters II - VII while general summaries are presented for the qualitative chapters VIII - XI. Included here for each quantitative chapter is a basic flow diagram which is briefly explained by component. More detailed flow charts, explanations of procedures, and the logic behind those procedures may be found in the individual technical chapters. The descriptions included in this chapter are provided only for purposes of illustrating interrelationships; they are not to be considered as descriptions of the actual steps necessary for technical analysis.

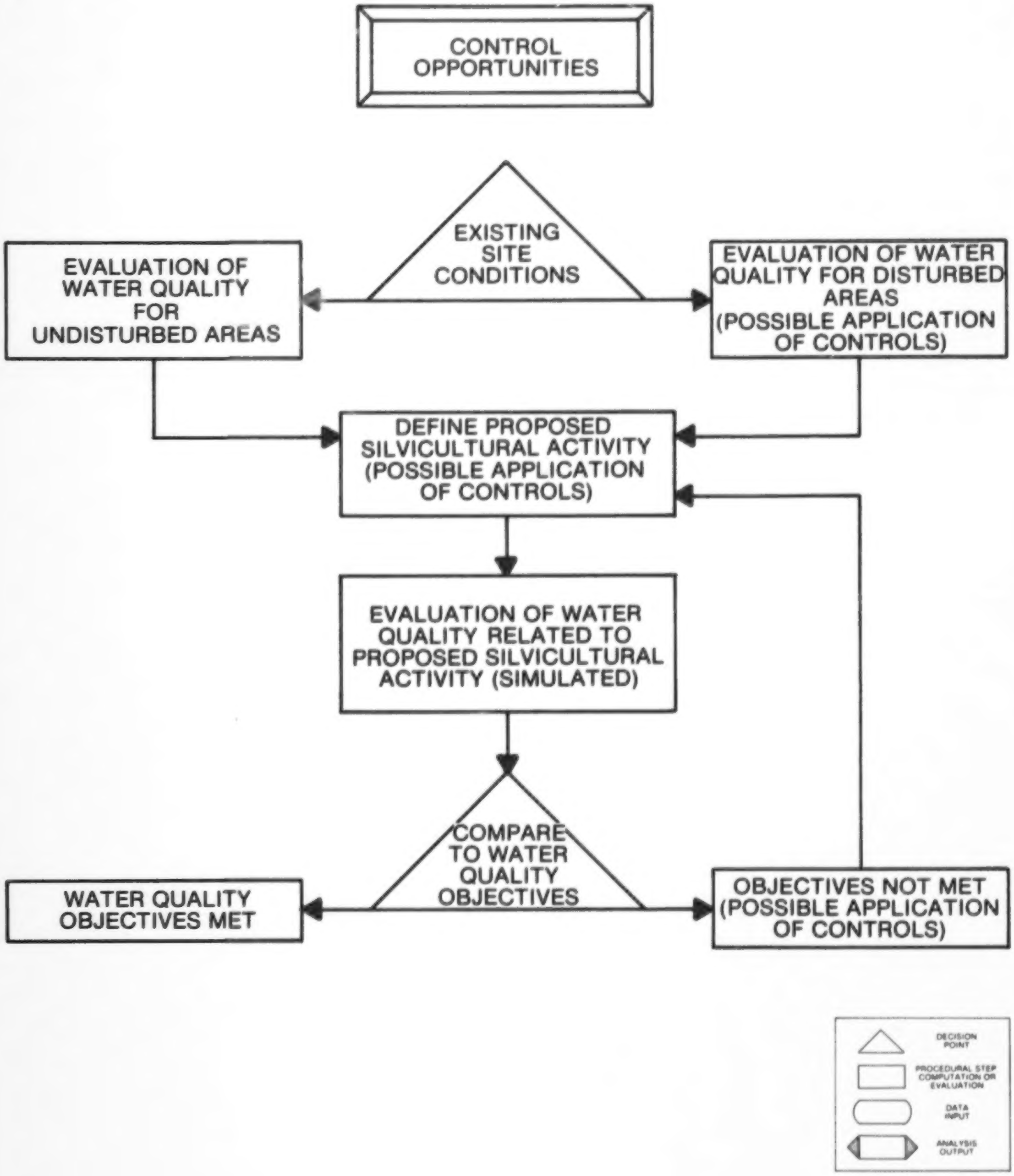
CONTROL OPPORTUNITIES
EXISTING SITE CONDITIONS
EVALUATION OF WATER QUALITY FOR UNDISTURBED AREAS
EVALUATION OF WATER QUALITY FOR DISTURBED AREAS (POSSIBLE APPLICATION OF CONTROLS)
DEFINE PROPOSED SILVICULTURAL ACTIVITY (POSSIBLE APPLICATION OF CONTROLS)
EVALUATION OF WATER QUALITY RELATED TO PROPOSED SILVICULTURAL ACTIVITY (SIMULATED)
COMPARE TO WATER QUALITY OBJECTIVES
WATER QUALITY OBJECTIVES MET
OBJECTIVES NOT MET (POSSIBLE APPLICATION OF CONTROLS)
DECISION POINT
PROCEDURAL STEP COMPUTATION OR EVALUATION
DATA INPUT
ANALYSIS OUTPUT

Figure I.1.—Generalized flow diagram for utilizing the control opportunities.

PROCEDURAL SUMMARY FOR CHAPTER II: CONTROL OPPORTUNITIES

Because silvicultural activities change certain landscape characteristics, primarily by causing soil disturbance, by altering the vegetative cover, and by changing local drainage patterns, the generation and transport of potential pollutants may be accelerated. Utilization of effective control techniques must then be considered.

In this handbook, control techniques are grouped into procedural, preventive, and mitigative categories. Procedural controls are those concerned with administrative actions. Preventive controls apply to the pre-implementation, planning phase of a silvicultural activity. Mitigative controls are physical, chemical, or vegetative measures applied to ameliorate problems that exist now, as well as those that may exist after a silvicultural activity has taken place.

Procedural, preventive, and/or mitigative control practices can be prescribed for various reasons, commonly including: (1) protection of water quality, (2) protection of capital investments such as roads and buildings, and (3) protection of site productivity. It may not be necessary to specifically formulate controls for water quality because the controls imposed for site protection may be adequate to meet water quality objectives. It is logical to first design a management plan to insure protection of site productivity and capital investments. If subsequent analyses show such a plan to be inadequate to meet water quality objectives, additional controls can be prescribed as needed.

The control measures are presented in four different ways. First, there is an activity-impact list that describes each silvicultural activity and its associated resource impacts. Next there is a list of resource impacts and possible control opportunities. Then each control is presented in a series of tables that display their relationship to the variables in each of the technical chapters. Finally, there is a description of each control and whether it is procedural, preventive, or mitigative.

Figure I.1 is a general flow diagram which summarizes the control selection process. This process is explained on the following pages.

EXISTING SITE CONDITIONS

The existing water quality must be known so that any changes in the quality following the proposed silvicultural activity can be evaluated. It is essential that some base be established so that impacts can be properly assessed. The existing water quality and site conditions should be measured whenever possible. If this is not feasible, then the existing water quality may be simulated using the procedures provided in the technical chapters or locally derived procedures that have proven effective.

The existing water quality will be greatly influenced by the history of the site, specifically natural (fires, floods, etc.) and man-induced (previous silvicultural operations, mining, etc.) disturbances. It must be determined if the site has been previously disturbed and if the disturbance is a contributing non-point source.

EVALUATION OF WATER QUALITY FOR UNDISTURBED AREAS

The measured or simulated water quality for an undisturbed site or a site that has previously been disturbed but no longer has contributing non-point sources is compared to the water quality objectives that have been established for the site. The objectives should not be exceeded. If they are exceeded, the objectives may be incompatible with the natural conditions and should be reviewed by the appropriate authority.

EVALUATION OF WATER QUALITY FOR DISTURBED AREAS (POSSIBLE APPLICATION OF CONTROLS)

The measured or simulated water quality for a disturbed site is compared to the water quality objectives that have been established for the site. If the objectives are exceeded, mitigative controls should be considered to ameliorate existing non-point sources. If the application of mitigative controls is not feasible, the objectives can be reviewed by the appropriate authority or the management of the site can be reevaluated.

DEFINE PROPOSED SILVICULTURAL ACTIVITY (POSSIBLE APPLICATION OF CONTROLS)

The control opportunities can be used as a reference to help in the formulation of the initial silvicultural plan. Mixtures of preventive, mitigative, and procedural controls can collectively become a silvicultural plan.

EVALUATION OF WATER QUALITY RELATED TO PROPOSED SILVICULTURAL ACTIVITY (SIMULATED)

The water quality that will follow the proposed silvicultural activity is estimated using the simulation procedures provided in the technical chapters or locally derived procedures that have proven effective. The same simulation procedures used for evaluating the existing conditions must be used to simulate the post-silvicultural activity water quality.

COMPARE TO WATER QUALITY OBJECTIVES

The estimated post-silvicultural activity water quality is compared to the established objectives. If the objectives are not exceeded, the proposed silvicultural activity is compatible and may be considered technically acceptable. If the objectives are exceeded, control opportunities should be evaluated and incorporated into a revised silvicultural plan where appropriate.

OBJECTIVES NOT MET (POSSIBLE APPLICATION OF CONTROLS)

When the proposed silvicultural activity results in non-point source pollution such that the water quality objectives are exceeded, control opportunities are evaluated that could be used to reduce these potential impacts. Preventive controls are initially evaluated, and those that are determined to be feasible are incorporated into the silvicultural activity plan. The revised silvicultural activity plan, including additional preventive controls, is evaluated using the simulation procedure. If the estimated water quality following the revised silvicultural activity meets the objectives the activity is considered technically acceptable from a water quality standpoint. If the objectives are exceeded, mitigative controls are evaluated; and those that are determined to be feasible are incorporated into the plan. The revised silvicultural activity plan, including both preventive and mitigative controls, is evaluated using the simulation procedure. The resulting estimated water quality is compared to the objectives. New controls may replace portions of the silvicultural plan or may be simply added to it to form a revised plan. It is recommended that several mixes of controls that meet water quality goals be formulated and presented to the manager.

WATER QUALITY OBJECTIVES MET

The proposed silvicultural activity is technically acceptable if the simulated water quality following that activity meets the objectives set for the stream or stream segment. Implementation follows the appropriate economic and social evaluations. If the proposed silvicultural activity would result in a degradation of water quality that would exceed the objectives, controls should be instituted and the plan revised to incorporate them. If the objectives would be exceeded even when controls have been considered, the objectives should be reviewed or the land uses for the site should be reevaluated.

PROCEDURAL SUMMARY FOR CHAPTER III: HYDROLOGY

The technical procedure begins with a description and an analysis of the hydrologic system of the area under study. Among the many variables considered in the evaluation are precipitation, evapotranspiration, soil water status, and streamflow. All of these variables influence, either directly or indirectly, the availability of energy for generation and/or transport of non-point source pollutants. Thus, results of the hydrologic analyses provide essential input for analysis of non-point source pollution potentials using methods described in subsequent chapters.

Hydrologic response to silvicultural activities varies greatly from region to region, as well as from site to site within a hydrologic region. For those hydrologic regions where snowfall dominates the hydrologic cycle, all pertinent processes, including snow redistribution, are discussed, and methods are presented for evaluation. However, in other parts of the country, some processes, such as snow redistribution are not significant. To account for these regional hydrologic differences, guidelines are presented for modifying the basic, more comprehensive analytic framework.

The objective of this evaluation is to estimate the amount of water potentially available for streamflow that is generated before and after a proposed silvicultural activity. Water available for streamflow is distributed either as an annual hydrograph in which 6-day average discharge values are plotted or as a flow duration curve in which 7-day average discharge values are calculated. Figure I.2 is a flow diagram that outlines the principal steps of the hydrology analysis. A description of the flow diagram follows.

DOMINANT PRECIPITATION

The hydrologic evaluation procedure for rainfall dominated regions differs from the hydrologic evaluation procedure for snowfall dominated regions. The predominant form of precipitation is determined, and the corresponding hydrologic evaluation procedure is selected.

RAINFALL DOMINATED AREAS

RAIN

If rainfall dominates the precipitation regime of the watershed of interest, the procedure as outlined below is applied.

SEASONAL PRECIPITATION

An estimate of seasonal precipitation is needed.

SEASONAL EVAPOTRANSPIRATION

Seasonal evapotranspiration is either estimated input or estimated using regional graphs which relate evapotranspiration to season of the year. Latitude is an additional variable needed for the Appalachian Mountain and Highland hydrologic region.

**SEASONAL EVAPOTRANSPIRATION
ADJUSTED FOR LEAF AREA
INDEX REDUCTION AND ROOTING DEPTH**

The leaf area index before and after the proposed silvicultural activity is estimated in the field or is derived from basal area-leaf area index relationships developed for the hydrologic region. A reduction in leaf area index results in less water lost through evapotranspiration, which in turn leaves more water available for streamflow. Rooting depth, a reflection of soil depth, influences the

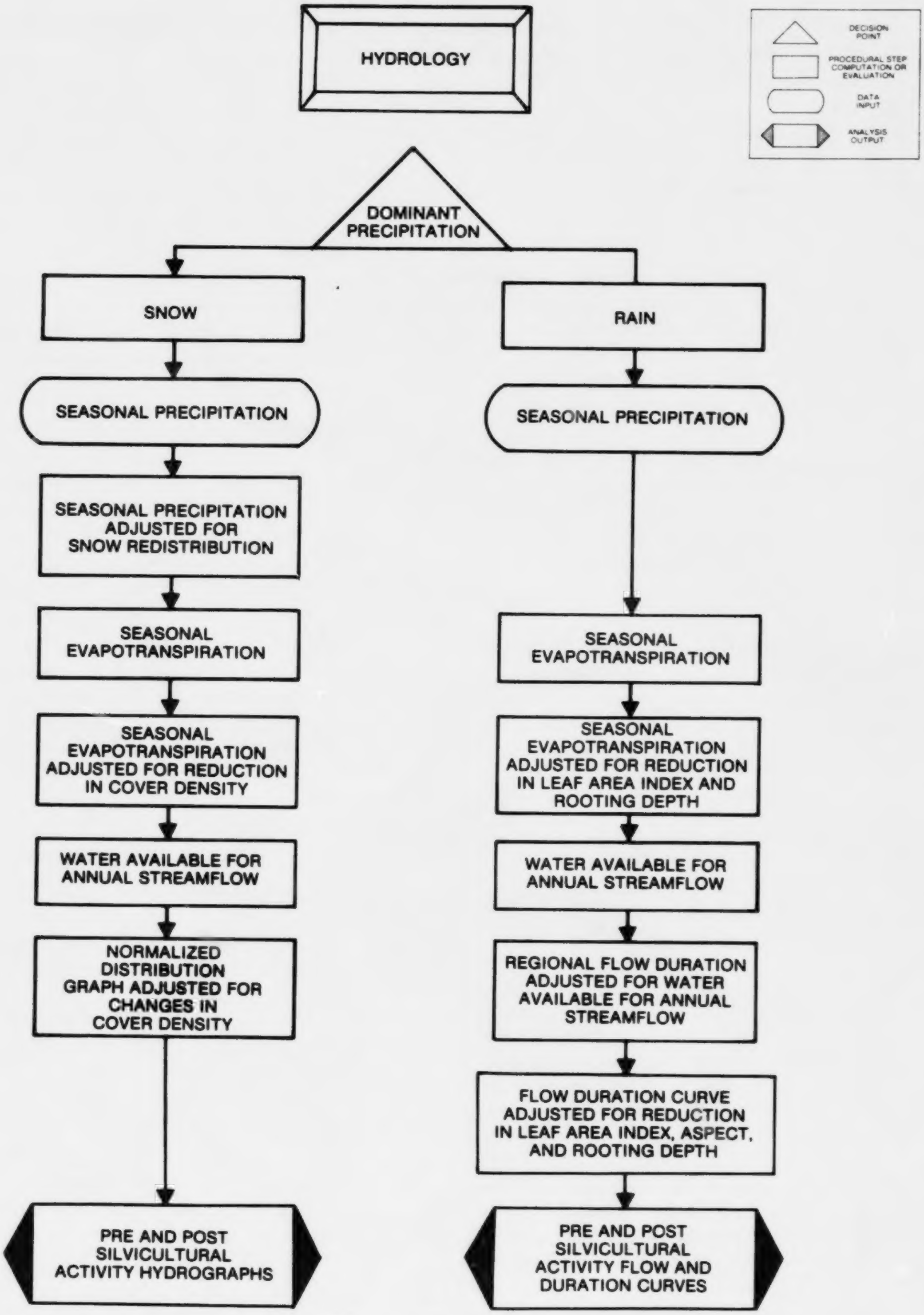
HYDROLOGY
DECISION POINT
PROCEDURAL STEP COMPUTATION OR EVALUATION
DATA INPUT
ANALYSIS OUTPUT
DOMINANT PRECIPITATION
SNOW
RAIN
SEASONAL PRECIPITATION
SEASONAL PRECIPITATION
SEASONAL PRECIPITATION ADJUSTED FOR SNOW REDISTRIBUTION
SEASONAL EVAPOTRANSPIRATION
SEASONAL EVAPOTRANSPIRATION
SEASONAL EVAPOTRANSPIRATION ADJUSTED FOR REDUCTION IN COVER DENSITY
SEASONAL EVAPOTRANSPIRATION ADJUSTED FOR REDUCTION IN LEAF AREA INDEX AND ROOTING DEPTH
WATER AVAILABLE FOR ANNUAL STREAMFLOW
WATER AVAILABLE FOR ANNUAL STREAMFLOW
NORMALIZED DISTRIBUTION GRAPH ADJUSTED FOR CHANGES IN COVER DENSITY
REGIONAL FLOW DURATION ADJUSTED FOR WATER AVAILABLE FOR ANNUAL STREAMFLOW
FLOW DURATION CURVE ADJUSTED FOR REDUCTION IN LEAF AREA INDEX, ASPECT, AND ROOTING DEPTH
PRE AND POST SILVICULTURAL ACTIVITY HYDROGRAPHS
PRE AND POST SILVICULTURAL ACTIVITY FLOW AND DURATION CURVES

Figure I.2.—Generalized flow diagram for the hydrology analysis.

amount of water available for evapotranspiration. Greater storage capacity results in more water being available to evapotranspiration loss.

WATER AVAILABLE FOR ANNUAL STREAMFLOW

Water available for seasonal streamflow is calculated by subtracting adjusted seasonal evapotranspiration from seasonal precipitation. Summation of water available for seasonal streamflows results in water available for annual streamflow.

REGIONAL FLOW DURATION CURVE ADJUSTED FOR WATER AVAILABLE FOR ANNUAL STREAMFLOW

A regional flow duration curve is selected from those provided or is supplied by the user. It is adjusted for the water available as annual streamflow prior to the silvicultural activity. The flow duration curve is based upon 7-day average discharge values.

FLOW DURATION CURVE ADJUSTED FOR REDUCTION IN LEAF AREA INDEX, ASPECT, AND ROOTING DEPTH

The post-silvicultural activity flow duration curve is calculated by adjusting the pre-silvicultural activity flow duration curve for the leaf area index reduction and aspect and rooting depth for the site. This is done with a least squares equation.

PRE- AND POST-SILVICULTURAL ACTIVITY FLOW DURATION CURVES

Pre- and post-silvicultural activity flow duration curves for 7-day average values are plotted.

SNOW DOMINATED AREA

SNOW

If snow dominates the precipitation regime of the watershed of interest, the procedure outlined below is applied.

SEASONAL PRECIPITATION

An estimate of seasonal precipitation is needed.

SEASONAL PRECIPITATION ADJUSTED FOR SNOW REDISTRIBUTION

For geographic areas in which snow redistribution is likely, the size and orientation of open areas must be known to evaluate the potential redistribution of snow. The amount of snow that is redistributed is determined largely by the size of the opening in the overstory.

SEASONAL EVAPOTRANSPIRATION

Seasonal evapotranspiration is either estimated input or estimated using regional graphs which relate precipitation and aspect to evapotranspiration. More water is lost by evapotranspiration from southern aspects than from northern aspects.

SEASONAL EVAPOTRANSPIRATION ADJUSTED FOR REDUCTION IN COVER DENSITY

A reduction in cover density may result in a reduction of evapotranspiration loss. Cover density changes may be estimated from basal area-cover density relationships.

WATER AVAILABLE FOR ANNUAL STREAMFLOW

Water available for seasonal streamflow is calculated by subtracting adjusted seasonal evapotranspiration from seasonal precipitation. Summation of water available for seasonal streamflow yields water available for annual streamflow.

NORMALIZED DISTRIBUTION GRAPH ADJUSTED FOR CHANGES IN COVER DENSITY

The normalized distribution graphs for the hydrologic region are selected. These graphs represent the distribution of annual flow as a percentage which occurs during consecutive 6 day intervals. Distribution graphs are presented for open and fully forested areas. Interpolation is necessary to obtain a normalized distribution graph for silvicultural treatments intermediate to fully forested and open.

PRE- AND POST-SILVICULTURAL ACTIVITY HYDROGRAPHS

Multiplication of values on the normalized distribution graph by the water available for annual streamflow and a conversion factor results in a hydrograph with units of cubic feet/second. Hydrographs for each silvicultural activity area are calculated separately and then summed to give the pre- or post-silvicultural activity hydrograph for the entire watershed.

PROCEDURAL SUMMARY FOR CHAPTER IV: SURFACE EROSION

A Modified Soil Loss Equation is presented as a method that may be used to estimate surface erosion from disturbed sites. Tables, graphs, and equations are used for the evaluation process. To apply these tools, information characterizing soils, topography, and ground cover must be obtained for a given site.

The objective of this analysis procedure is to estimate the quantity of accelerated soil loss (tons/year) and the amount that might reach a stream under given silvicultural activity conditions. Soil loss is based on four factors to evaluate the detachment of soil particles on a site. If this detached material is not delivered to a water course, there will be no degradation of water quality.

Estimates of sediment which may be delivered to a stream system are based on eight factors. The model delivers eroded material across a reference boundary, such as out of a clearcut block and into an adjacent area.

Figure I.3 is a flow diagram that outlines the principal steps involved in a surface erosion evaluation. A narrative explaining the flow diagram follows.

ONSITE ESTIMATED SURFACE SOIL LOSS

Estimated potential surface erosion is based upon a modified version of Wischmeier and Smith's Universal Soil Loss Equation. Modifications were made to adopt their equation to forested situations and silvicultural activities. The modified equation uses the four following factors: (1) rainfall, (2) soil erodibility, (3) slope gradient and slope length of disturbed site, and (4) the vegetation present and management applied. The solution of the equation gives estimated soil loss in tons/acre/year. When multiplied by the acres disturbed, the result is tons/year.

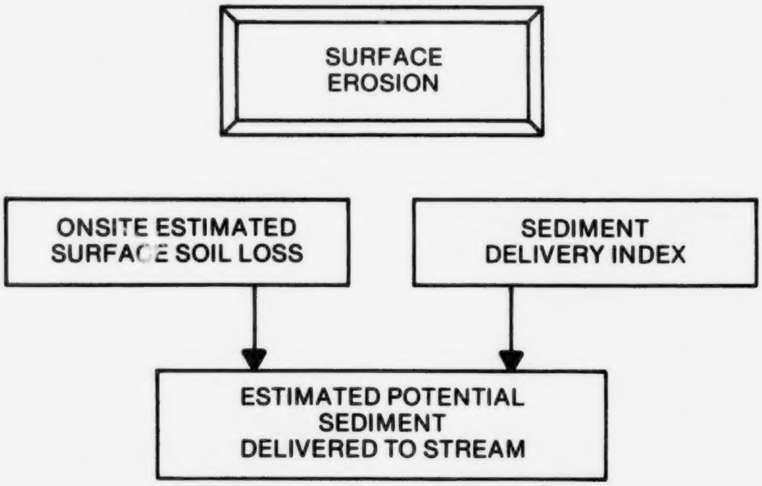
SURFACE EROSION
ONSITE ESTIMATED SURFACE SOIL LOSS
SEDIMENT DELIVERY INDEX
ESTIMATED POTENTIAL SEDIMENT DELIVERED TO STREAM

Figure I.3.—General flow diagram for the surface erosion analysis.

SEDIMENT DELIVERY INDEX

The delivery index is used to estimate the amount of eroded material on a disturbed site that might reach the closest stream channel. The index is estimated from factors that are assumed to control sediment delivery: (1) available water for surface runoff, (2) texture of the eroded material, (3) amount of ground cover present in the area between the disturbed site and stream channel, (4) overall slope shape, (5) slope gradient of the land, (6) distance material must travel between the disturbed site and stream channel, (7) surface roughness, and (8) special characteristics of a local site, if applicable.

The delivery index represents the fraction of the available sediment which might reach a stream.

ESTIMATED POTENTIAL SEDIMENT DELIVERED TO STREAM

The onsite annual estimated surface soil loss in tons/year is multiplied by the delivery index to obtain an estimate of the quantity of material that may be delivered to a stream. The result is in tons/year. This estimated value is required as input into the analysis of total potential sediment production (chapter VI).

PROCEDURAL SUMMARY FOR CHAPTER V: SOIL MASS MOVEMENT

The chapter on soil mass movement provides a method for identifying and qualitatively assessing the site factors and management activities that increase the hazard of soil mass movement. Soil mass movements are classified into two general types: (1) the debris avalanche–debris flow, and (2) the slump-earthflow. Overall ratings can be made in terms of high, moderate, or low hazard.

Only material that is delivered directly to a channel system is considered under soil mass movement. It is recognized that mass movement produces a supply of erodible material that may reach stream channels at a much later date than the actual mass movement event and that considerable onsite resource damage may occur. Unless the material reaches a channel, however, no water quality degradation would occur. The effect that any failure will have on water quality degradation depends primarily on the size and volume of material reaching a channel and the energy of the stream system for transport.

The information obtained from the soil mass movement evaluation is used as input to the total potential sediment estimation (chapter VI).

The objective of this analysis procedure is to estimate the hazard of a soil mass movement and to estimate the quantity of mass movement material, in tons, that may be deposited in a water course given the pre- and post-silvicultural activity conditions. Silvicultural activities may have the potential to increase the hazard and/or size of a mass movement occurrence as well as the amount of material that may reach a stream.

Figure I.4. outlines the principal steps for the soil mass movement analysis. A description of those steps follows.

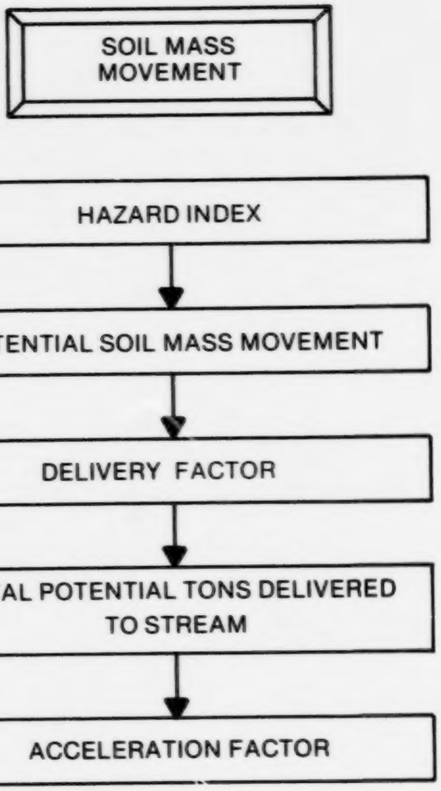
SOIL MASS MOVEMENT
HAZARD INDEX
POTENTIAL SOIL MASS MOVEMENT
DELIVERY FACTOR
TOTAL POTENTIAL TONS DELIVERED TO STREAM
ACCELERATION FACTOR

Figure I.4.—General flow diagram for the soil mass movement analysis.

HAZARD INDEX

The hazard index of a soil mass movement occurrence is determined by the type of movement, slump-earthflow versus debris avalanche-debris flow, and a variety of onsite parameters and silvicultural activities. The more critical factors include: (1) slope gradient, (2) slope configuration, (3) soil depth, (4) soil texture, (5) bedding structure and orientation, (6) precipitation, (7) drainage, (8) vegetation, (9) harvest methods, and (10) roads. The result of this subjective evaluation is a hazard index—high, medium, or low. The hazard index indicates the intensity of analysis that may be necessary to adequately evaluate mass movement.

POTENTIAL SOIL MASS MOVEMENT

The potential quantity of mass movement, in tons, that could occur is estimated. The average volume of mass movement that has occurred on the site in the recent past is determined by type (slump-earthflow, or debris avalanche-debris flow), or a subjective estimate is made where there is no history of mass movement. The volume of material is converted to tons based upon the type and bulk density of material that would be carried in a mass movement event.

DELIVERY FACTOR

The quantity of material in tons that would be delivered to a stream is estimated according to: (1) type of mass movement, (2) position of failure on slope, (3) slope gradient, and (4) uniformity of slope. The delivery factor is expressed as a percent.

TOTAL POTENTIAL TONS DELIVERED TO STREAM

The potential mass movement in tons is multiplied by the delivery factor to estimate the quantity of material that would enter a stream. The results are expressed in tons.

ACCELERATION FACTOR

For determination of the quantity of soil mass movement delivered to a stream channel due to silvicultural activity, measurements should be made on an area with similar characteristics and a history of silvicultural activity comparable to that being proposed for the area under analysis. The ratio of soil mass movement due to silvicultural activity to that from natural causes is given as an acceleration factor. The potential increase in soil mass movement due to implementation of the proposed silvicultural activity can be estimated by multiplying the acceleration factor by the natural soil movement occurring on the area. This estimated value is used as input into the total potential sediment analysis (chapter VI).

PROCEDURAL SUMMARY FOR CHAPTER VI: TOTAL POTENTIAL SEDIMENT

This chapter provides an analytical framework for evaluating potential changes in sediment discharge associated with silvicultural activities. Changes in sediment discharge due to introduced sources (surface erosion and soil mass movement) and flow related increases are evaluated.

The quantitative evaluation of suspended sediment and bedload sediment is based on locally derived regression equations. These procedures are designed to be used below the silvicultural activity, generally at the mouth of third order drainages. Impacts to channel geometry are qualitatively evaluated using bedload transport-stream power curves developed from local data.

Figure I.5 outlines the principal steps for the total potential sediment analysis.

SUBDRAINAGE AND STREAM REACH CHARACTERIZATION

After a suitable site has been selected, data can be collected for the suspended sediment and bedload rating curves. This data should be obtained on a third order drainage that is below the proposed silvicultural activity. To evaluate effects of channel encroachments, stream reaches immediately below or adjacent to the silvicultural activity should be selected for a quantitative evaluation.

The soil mass movement and surface erosion analyses, as outlined in chapters IV and V, characterize the subdrainage with respect to the introduced sources that are a result of the proposed silvicultural activity and provide input into the total potential sediment calculations.

STREAMFLOW HYDROGRAPHS OR FLOW DURATION CURVES

The streamflow hydrographs or flow duration curves for the pre- and post-silvicultural activities are obtained from "Chapter III: Hydrology."

SEDIMENT RATING CURVES AND CHANNEL STABILITY

Measured suspended sediment concentrations and concurrent stream discharges for a wide range of flows collected on the third order drainage are plotted. The relationship can then be expressed mathematically in a sediment rating curve. Using the pre- and post-silvicultural activity hydrographs, the change in suspended sediment discharge is calculated in tons/year. Appropriate data should also be collected on the third order stream reach so that a channel stability rating may be made. This data may be used to form a basis for determining the limits for stream stability changes.

INTRODUCED SOURCE SOIL MASS MOVEMENT COARSE AND FINE

The output from the soil mass movement analysis described in chapter V is expressed in terms of total potential tons of material delivered to the stream. The quantity of material is an estimate of the total potential soil mass movement material that may be delivered to the closest available drainageway following the silvicultural activity. The total volume of material is expressed as the percentage of coarse and of fine (wash load) material. Assuming this material is all available during the first year after the activity, the percent of fines can be used as a part of the total suspended sediment that is compared with the water quality objective.

The coarse material is used with the bedload-transport stream power curve to provide a qualitative estimate of potential stream channel changes. The total volume is one component of the total sediment of all sources that are available within the watershed.

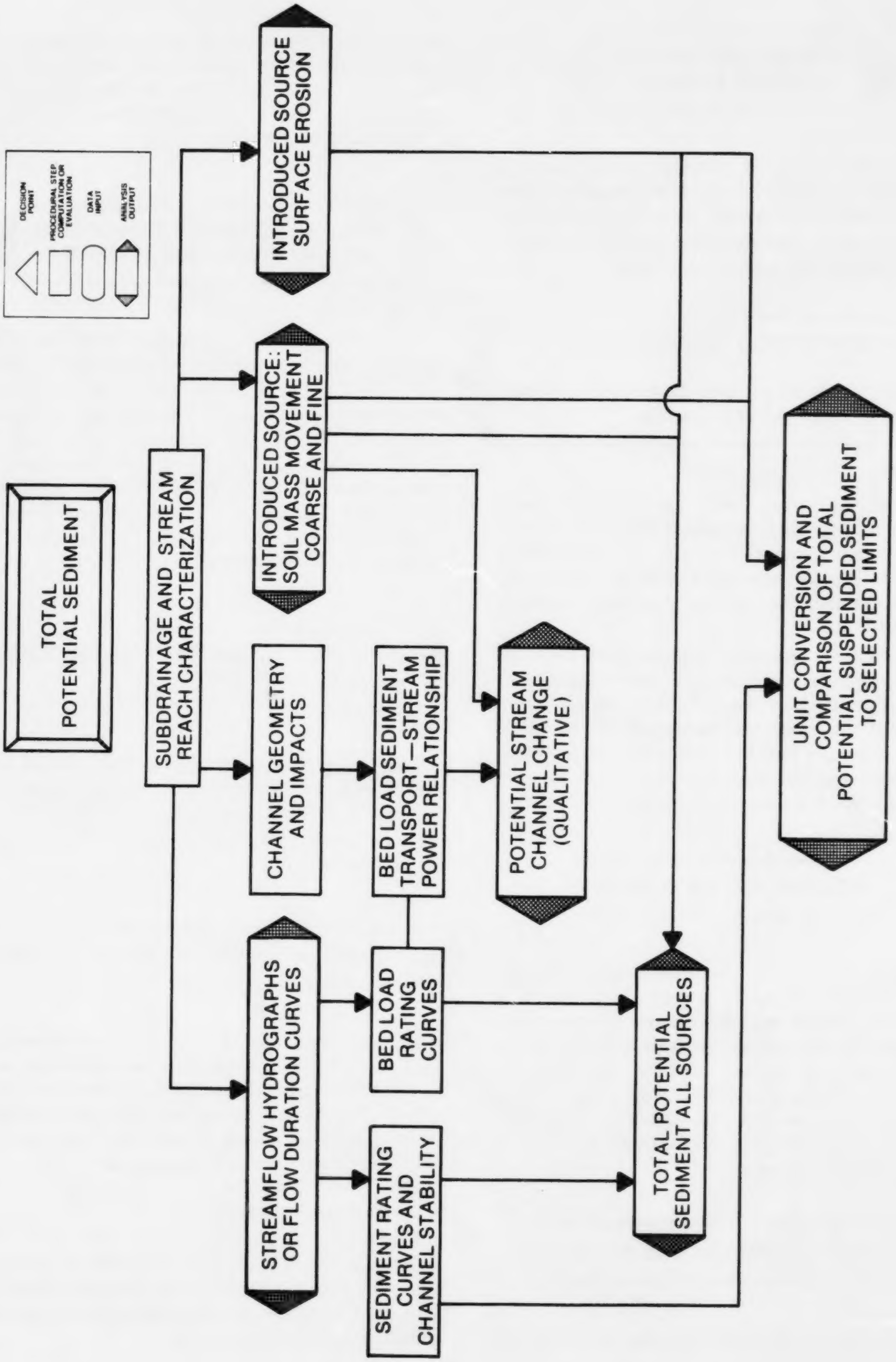
TOTAL POTENTIAL SEDIMENT
DECISION POINT
PROCEDURAL STEP COMPUTATION OR EVALUATION
DATA INPUT
ANALYSIS OUTPUT
SUBDRAINAGE AND STREAM REACH CHARACTERIZATION
STREAMFLOW HYDROGRAPHS OR FLOW DURATION CURVES
CHANNEL GEOMETRY AND IMPACTS
INTRODUCED SOURCE: SOIL MASS MOVEMENT COARSE AND FINE
INTRODUCED SOURCE SURFACE EROSION
SEDIMENT RATING CURVES AND CHANNEL STABILITY
BED LOAD RATING CURVES
BED LOAD SEDIMENT TRANSPORT—STREAM POWER RELATIONSHIP
POTENTIAL STREAM CHANNEL CHANGE (QUALITATIVE)
TOTAL POTENTIAL SEDIMENT ALL SOURCES
UNIT CONVERSION AND COMPARISON OF TOTAL POTENTIAL SUSPENDED SEDIMENT TO SELECTED LIMITS

Figure I.5.—General flow diagram for the total potential sediment analysis.

INTRODUCED SOURCE SURFACE EROSION

This is the volume of delivered eroded material introduced as a result of the silvicultural activity. It is expressed as tons/year. This volume is added to the total suspended sediment increases and compared to the water quality objective.

UNIT CONVERSION AND COMPARISON OF TOTAL POTENTIAL SUSPENDED SEDIMENT TO SELECTED LIMITS

Selected maximum limits for suspended sediment in milligrams/liter, as set by water quality objectives, are converted to tons for comparative purposes. Typical objectives may be state sediment standards or stream channel stability threshold limits.

All potential suspended sediment increases due to streamflow increases, surface erosion, and wash load (silts and clays) contributed from soil mass movement processes are combined. If the water quality objective has been exceeded, appropriate controls for the introduced sources must then be identified and a reanalysis performed.

BEDLOAD RATING CURVES

Applying the same procedures used for the suspended sediment rating curves, a bedload rating curve for the third order stream reach is prepared. Pre- and post-silvicultural activity hydrographs or flow duration curves are used to determine the flow-related changes in bedload discharge. These curves are also used to develop bedload-stream power relationships for a qualitative evaluation of stream channel response.

CHANNEL GEOMETRY AND IMPACTS

Changes in the variables affecting stream power are evaluated based on the potential changes anticipated for given silvicultural activities and measured channel characteristics. The calculations are utilized to obtain qualitative interpretations of stream channel response.

BEDLOAD SEDIMENT TRANSPORT-STREAM POWER RELATIONSHIP

This relationship is developed from measured bedload data and channel geometry for the third order stream. The variables are: (1) width, (2) surface water slope, (3) particle size of bed material in transport, (4) bedload transport rates, and (5) stream discharge, all obtained over a wide range of flows. This relationship is used to determine qualitative changes in channel response from introduced soil mass movement material and changes in stream power.

POTENTIAL STREAM CHANNEL CHANGES (QUALITATIVE)

This is a qualitative output of the changes that can be expected in terms of scour and deposition within a channel. These changes are due to alterations in stream power and/or introduced soil mass movement material.

TOTAL POTENTIAL SEDIMENT ALL SOURCES

This is a composite of increases in sediment discharge made available within the watershed as a result of silvicultural activity. It is composed of all sources of sediment including: (1) suspended sediment due to increased stream flow, (2) bedload sediment due to increased stream flow, (3) surface erosion from all sources, and (4) soil mass movement from all sources.

This is used to compare the pre-activity to post-activity sediment discharge. An index of the total potential increases can be determined. Although expressed in tons/year, temporal and spatial distributions are not analyzed.

PROCEDURAL SUMMARY FOR CHAPTER VII: TEMPERATURE

Increased water temperature can be either beneficial or detrimental to the water resource. For streams that are cooler than optimum, a moderate increase in temperature could increase productivity and have a beneficial effect on the aquatic environment. However, streams having temperatures that approach critical threshold limits during the summer months could reach lethal levels if these temperatures were increased.

When the removal of shading vegetation along stream channels increases the stream's exposure to heating from solar radiation, it also increases the potential for a rise in water temperature. The magnitude of the increase is a function of the following variables: (1) the amount of canopy removed, (2) length of time the stream is exposed to direct solar radiation, (3) streambed material, (4) stream width, (5) stream discharge, and (6) subsurface inflow. The described procedure, based upon the use of a temperature model, provides a means of assessing the influence of these variables as they are affected by silvicultural activities and control practices. Downstream temperature changes are evaluated using a mixing ratio.

The objective of this procedural analysis is to estimate the maximum potential daily temperature increase (in degrees Fahrenheit) above the pre-silvicultural activity water temperature. Silvicultural activities may remove vegetation that provides shade to the water surface. The loss of this shading may result in increased water temperatures.

Figure I.6 outlines the principal steps in evaluating the potential change in stream temperature.

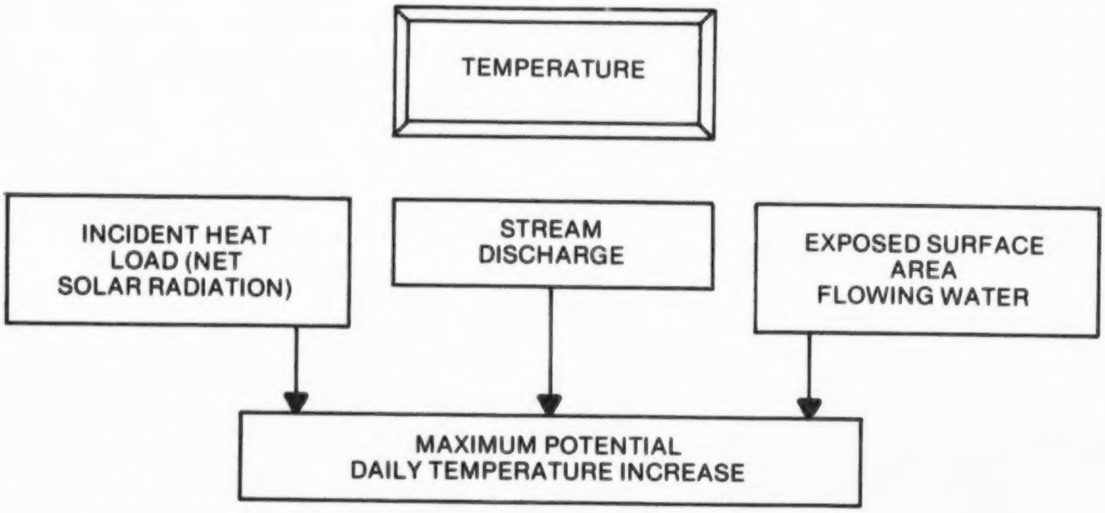
TEMPERATURE
INCIDENT HEAT LOAD (NET SOLAR RADIATION)
STREAM DISCHARGE
EXPOSED SURFACE AREA FLOWING WATER
MAXIMUM POTENTIAL DAILY TEMPERATURE INCREASE

Figure I.6.—General flow diagram for the temperature analysis.

INCIDENT HEAT LOAD (NET SOLAR RADIATION)

Incident heat load (net solar radiation), H, is the source of heat influx that causes the water temperature to increase. The amount of solar radiation that is received by a stream from the sun is determined primarily by: (1) latitude of the site, (2) time of year, and (3) time of day. These variables have been combined in figures and graphs and an estimated value of net solar radiation in BTU/ft^2-minute is obtained.

STREAM DISCHARGE

The magnitude of the water temperature increase is determined in part by the volume of water that is flowing in the stream. Discharge should be measured during the time of year when water temperature is critical for pre-silvicultural activity conditions. However, if the hydrology analysis (chapter III) indicates that there may be a significant change in discharge during this critical time period following the silvicultural activity, the discharge estimated by the hydrology analysis should be used. Discharge is expressed as cubic feet/second.

EXPOSED SURFACE AREA FLOWING WATER

Net solar radiation acts as a direct heat influx only when the radiation strikes the exposed water surface. Shading keeps this radiation from striking the water surface. However, because streams are generally not completely shaded, some solar radiation strikes the water surface even in the undisturbed condition. Silvicultural activities may not completely expose the stream. Brush, shrubs, noncommercial tree species, and/or trees remaining after a portion of a stand is cut may provide some shade. The surface area of a stream exposed by the silvicultural activity must be estimated in square feet.

MAXIMUM POTENTIAL DAILY TEMPERATURE INCREASE

Maximum potential daily temperature increase can be estimated by evaluating the factors noted above: (1) net solar radiation, (2) discharge, and (3) exposed surface area of flowing water. The estimated temperature increase above the pre-silvicultural activity water temperature is given in degrees Fahrenheit. This estimated increase is compared to water quality objectives for stream temperature.

SUMMARY OF CHAPTER VIII: PROCEDURAL EXAMPLES

An example is provided to illustrate the procedures that have been described in the preceding technical chapters. Two hypothetical watersheds with proposed silvicultural activities, one in a rain-dominated area and one in a snow-dominated area, are presented. Each step in the various procedures is described, along with the data needs and any subjective evaluation that is required. Use of the control chapter is also illustrated to select preventive and mitigative controls.

SUMMARY OF CHAPTER IX: DISSOLVED OXYGEN AND ORGANIC MATTER

Silvicultural activities can potentially reduce the concentration of dissolved oxygen in the water to the lethal level for some aquatic species through introduction of organic materials and increased water temperatures. The state-of-the-art is such that it is not possible to rigorously quantify the impacts associated with the introduction of organic material to the aquatic system. This chapter describes, in general terms, the processes involved and identifies situations which may create undesirable consequences.

Water temperature, elevation, aeration potential, type of aquatic life present, and stream uses are considered in the discussion. Essential control measures can then be selected to protect the values involved.

SUMMARY OF CHAPTER X: NUTRIENTS

Nitrogen and phosphorus are the nutrients generally cited as having the greatest potential for impacting water quality in a forest environment. Streams may show symptoms of overenrichment if there is a continuous supply of nutrients and substantial periods of low water flow, but generally there is minimal opportunity for buildup of nutrients in streams due to continual transport by water.

The discussion in this chapter places major emphasis on the sources of nitrogen and phosphorus in the forest environment, the intracycle processes in the forest, and the nitrogen and phosphorus outputs from the forest.

Models for predicting soluble and insoluble nutrient losses from silvicultural activities are not sufficiently developed and tested for general application. Therefore, only qualitative guidelines are given for evaluating soluable nutrient changes within a system.

SUMMARY OF
CHAPTER XI: INTRODUCED CHEMICALS

Fertilizers and pesticides (insecticides, herbicides and fungicides) are chemicals commonly introduced into a watershed as part of silvicultural activities. Introduced fertilizers enter a water course by direct application of fertilizer to the water surface or by leaching and subsequent subsurface flow of dissolved compounds or decomposition products. The impact of pesticides on water quality depends primarily on the following five factors: (1) toxicity to man and aquatic organisms, (2) mobility, (3) persistence, (4) accuracy of placement, and (5) orientation to streams.

This chapter is directed primarily to a discussion of the types of pesticides and fertilizers used, and to the types of impacts that have been observed onsite and in the aquatic ecosystem. The disposition of introduced chemicals in the forest environment is discussed. Because procedures for quantifying the impacts have not been developed for general application, no attempt has been made to quantify control effectiveness.

Chapter II

CONTROL OPPORTUNITIES

this chapter was prepared by:

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with major contributions from a committee
including three silviculturists, two foresters,
one logging engineer, one civil engineer,
one hydrologist and one soil scientist

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INTRODUCTION

This chapter lists demonstrated, effective control practices and suggests ways to choose mixtures of these and similar controls for the prevention and mitigation of resource impacts. Because economic and social analyses are not discussed in this handbook, the mixtures of controls presented in this chapter do not represent a "Best Management Practice" (BMP). These control mixtures form only the technical base for the BMP.

Control measures can be prescribed for various reasons, including: (1) protection of site productivity, (2) protection of capital investments, such as roads and buildings, and (3) protection of water quality. Many of the control practices can be used for all three reasons. For this reason, it may not be necessary to specifically formulate controls for water quality if controls imposed for site protection are adequate to meet water quality objectives.

DISCUSSION

CONTROLS TERMINOLOGY

Distinction is made between three classes of controls — procedural, preventive, and mitigative — according to the method of operation. These terms are further defined as:

Procedural controls. — Procedural controls are administrative actions or sanctions that result in reduced generation of transport of pollutants. Examples: enforcement of standards, bonding of operators.

Preventive controls. — Preventive controls apply to the pre-implementation phase of an operation. These controls are planning oriented and involve stopping or changing a planned activity before a pollution-causing disturbance is allowed to occur. Example: the location of roads and landings away from the stream.

Mitigative controls. — Mitigative controls include vegetative, chemical or physical measures which alter the response of the water-disturbing activity after it has occurred. Example: the revegetation of disturbed areas.

POTENTIAL RESOURCE IMPACTS

A resource may be damaged by impacts upon it if natural processes are altered. Potential resource impacts are defined and the related processes are discussed in the following paragraphs. These 11 impacts are considered to be those most important in terms of non-point source water pollution and silvicultural activities. They are listed alphabetically and not necessarily by order of importance.

Aerial drift and application of chemicals. — Any chemical pesticides, herbicides, or fertilizers allowed to fall or wash into a stream can affect dissolved oxygen, nutrient levels, and other characteristics of that stream.

Bare soil. — Bare soil is a result of reduction in vegetative ground cover, rock, and litter. Some bare soil is unavoidable as a result of silvicultural activities.

Bare soil can lead to reduced infiltration of water into the soil profile caused by surface crusting and the attendant soil compaction. This, in turn, can cause surface runoff and water concentration and finally lead to rill or gully erosion. In addition, some changes in the onsite chemical balance may occur as a result of increased nutrient leaching and a reduction in organic matter.

Channel gradient change. — A change in channel slope can alter energy relationships which, in turn, can cause channel scour deposition. Debris dams or improperly placed culverts in streams can cause changes in channel gradient.

Compaction. — "Soil compaction is the packing together of soil particles by instantaneous forces exerted at the soil surface resulting in an increase in soil density through a decrease in pore space. This loss of pore space reduces infiltration capacity, and water movement through the soil is slowed. Then surface runoff may occur more frequently and may increase in volume. Erosion begins; and, once begun, may be difficult to stop. In a logging operation, the extent of compaction depends on the type of equipment, the terrain over which the logs are skidded or hauled, the frequency of travel, and the type of soil and its moisture content." (Lull 1959).

Debris in channel. — Debris in the channel refers to those obstructions in a stream channel caused by silvicultural activities. Such obstructions include debris dams (logs, slash, rock, etc.), fill slope encroachment from roads, or any material deposited in the channel due to silvicultural activities.

Such obstructions can deflect flow which can erode streambanks. Debris can form dams and the attendant water impoundment can cause local flooding. In addition, during high flow, debris can float downstream, accumulate against bridges, and become a threat to bridge safety. Introduction of vegetative debris, in particular needles or leaves, can increase Biochemical Oxygen Demand (BOD) (Currier 1974, Ponce 1974). Encroachments and debris dams can alter velocity, thereby influencing exposure time to solar radiation with a resultant water temperature increase.

Excess water. — Excess water is the increase in channel flow resulting from evapotranspiration reduction due to canopy removal. Excess water can also be caused by reduced infiltration rates into bare or compacted soil. This water results in increased energy and consequent bank and channel erosion.

Onsite chemical balance changes. — Silvicultural activity can result in release of chemicals which, in turn, may leach or wash into streams, thereby affecting nutrient and Biochemical Oxygen Demand (BOD) levels in the water. For example, chemical balance changes may result from burning, excessive amounts of woody material, or crankcase oil spills.

Slope configuration changes. — Slope configuration changes refer to an alteration of the land slope. This may occur in roadbuilding when cuts and fills are constructed for the road base, contour terracing, etc. Slope configuration changes can weaken slopes, lead to mass failure, and intercept subsurface flow.

Stream shading changes. — Stream shading changes occur when trees and/or understory vegetation that contribute to the shading of water in streams are removed. Exposing streams to direct solar radiation increases water temperature.

Vegetative change. — Vegetative change includes the removal of vegetative ground cover, canopy cover, or a change in vegetative type.

Vegetative change has numerous potential effects, including changes in evapotranspiration, soil protection, soil mass movement, stream shading, and water velocity of over-the-ground flow on disturbed sites. These changes affect the hydrologic processes, surface erosion, soil mass movement, stream temperature, and ditch and stream velocity. Vegetative manipulation may also affect stream nutrients.

Water concentration. — Water concentration occurs when water is intercepted and allowed to converge instead of infiltrating into the soil or spreading naturally. Water concentration, as a resource impact, is closely related to bare soil, compaction, and excess water. Concentrated water moves with greater force than does the same amount of water in sheet flow. Concentrated flow may cause rill erosion, thus increasing the probability of gully erosion.

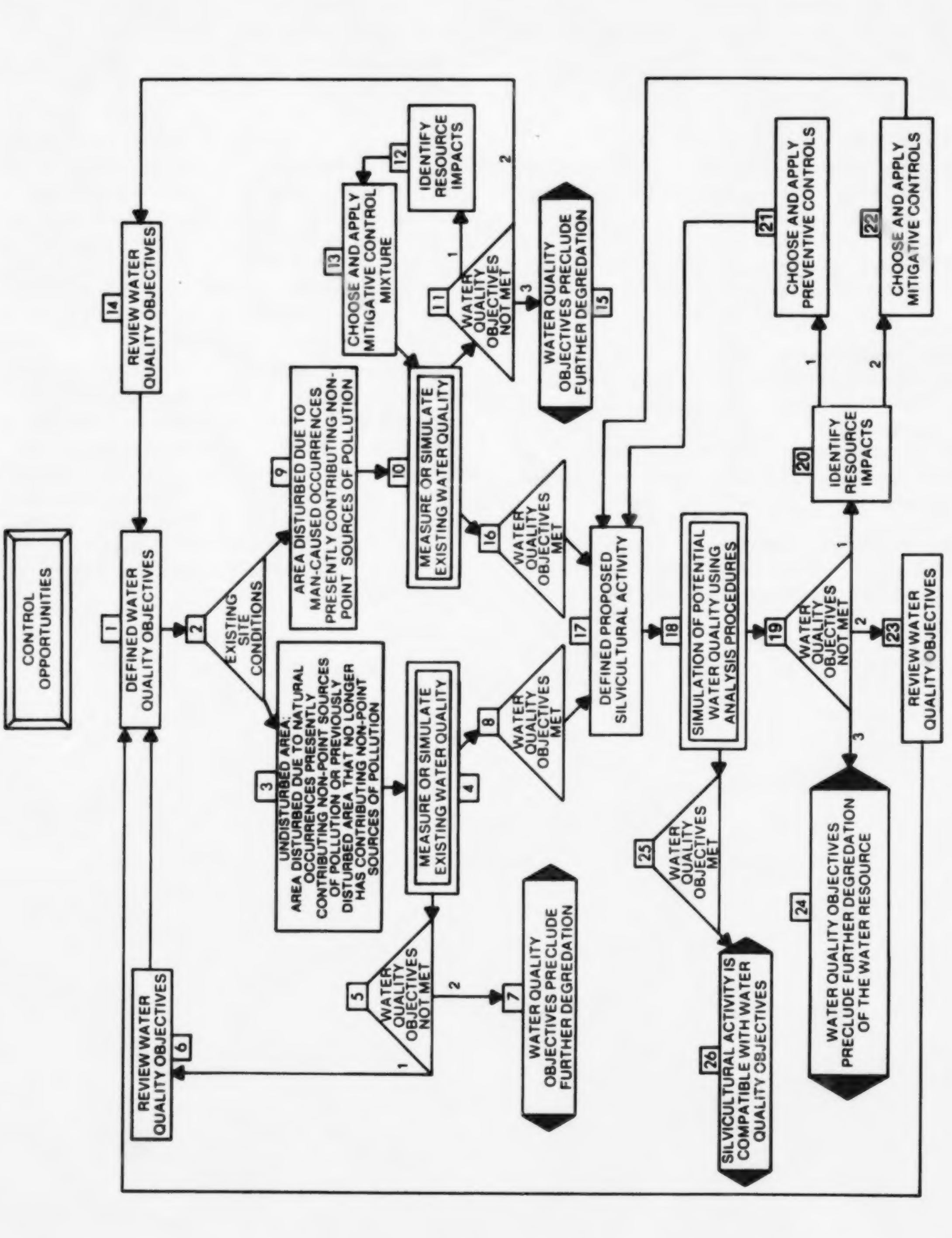
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Figure II.1.—Procedural flow chart for utilizing control opportunities.

THE PROCEDURE

To meet established water quality objectives, existing water quality must be known. Then, the proposed silvicultural activity must be evaluated and the water quality that would result from it estimated. By comparing the water quality objectives with the existing and estimated water resource conditions, the degree and type of control necessary to meet the objectives can be determined.

The overall strategy for assessing and evaluating alternative control opportunities is described using a procedural flow diagram (fig. II.1), with a verbal description of the procedure. The controls procedure explains how to use the four major portions of the control information in the handbook's simulation procedure. Section A relates various silvicultural activities to the potential adverse resource impacts that may be associated with each activity. Section B suggests control opportunities for each potential resource impact. Section C indicates the relationship between resource impacts and simulation variables, and between control opportunities and the simulation variables. Section D describes all control opportunities in more detail. Appendix II.A presents three cases illustrating how to use the control information in relation to the overall use of this handbook.

PROCEDURAL DESCRIPTION

The following paragraphs describe the procedural flow chart in more detail. The indicated numbers do not represent sequential steps, but act as points of reference back to the flow chart, figure II.1.

DEFINED WATER
QUALITY OBJECTIVES
1

Prior to any evaluation of the potential change in the water resource due to a proposed silvicultural activity, water quality objectives must be specified. These objectives are generally established by legislative or regulatory authority. To ascertain if a potential change caused by a proposed silvicultural activity is acceptable, the change must be compared with water quality objectives.

EXISTING
SITE
CONDITIONS
2

At this point, a decision must be made as to whether any disturbance in a watershed is natural or man-caused.

The existing condition of the water resource before any proposed silvicultural activity takes place must be determined through the use of aerial photos, historical records, or on-the-ground observations.

UNDISTURBED AREA,
AREA DISTURBED BY
NATURAL OCCURRENCES
PRESENTLY CONTRIBUTING NON-POINT
SOURCES OF POLLUTION, OR
PREVIOUSLY DISTURBED AREA
THAT NO LONGER HAS CONTRIBUTING
NON-POINT SOURCES OF POLLUTION
3

The water resource condition in areas that have never been subjected to man-induced disturbances and in areas that have at one time been disturbed but have recovered sufficiently and no longer have contributing non-point sources of pollution is determined by the existing vegetation, soil, and geology. This represents the natural base condition of the water resource.

MEASURE OR SIMULATE
EXISTING WATER QUALITY
4

Existing water quality should be measured using a sampling scheme that enables the water quality parameters of interest to be evaluated. If measured data are not available and cannot be feasibly collected, the existing condition can be estimated using analysis procedures presented in subsequent chapters or locally derived methods.

**WATER QUALITY
OBJECTIVES
NOT MET
5**

The existing water quality is compared with the water quality objectives. If the existing condition exceeds the objectives, further evaluation is required.

**REVIEW WATER
QUALITY OBJECTIVES
6**

First of two possible actions.

If the existing condition of the water resource does not meet the objectives, the objectives should be reviewed and possibly revised by the appropriate authority.

**WATER QUALITY OBJECTIVES
PRECLUDE FURTHER DEGRADATION
7**

Second action.

Because the objectives are presently exceeded by the existing water resource condition, no silvicultural activity should be considered that would result in any further degradation. Alternative land use management of the watershed may be necessary.

**WATER
QUALITY
OBJECTIVES
MET
8**

If the existing water resource condition meets water quality objectives, a proposed silvicultural activity plan can be formulated.

**AREA DISTURBED BY MAN-CAUSED
OCCURRENCES PRESENTLY CONTRIBUTING
NON-POINT SOURCES OF POLLUTION
9**

The water quality in areas that have been subjected to man-induced disturbances may be determined in great part by the non-point source pollution coming from the disturbed sites. It is, therefore, necessary to evaluate the impact of these contributing non-point sources to ascertain whether the existing water quality objective is being met.

**MEASURE OR SIMULATE EXISTING
WATER QUALITY
10**

Existing water quality should be measured using a sampling scheme that enables the water quality parameters of interest to be evaluated. If measured data are not available and cannot be feasibly collected, the existing condition of the water resource can be estimated by using analysis procedures presented in subsequent chapters or locally derived methods.

**WATER
QUALITY OBJECTIVES
NOT MET
11**

The existing water quality is compared with the given water quality objectives. If the existing quality exceeds the objective, further evaluation is required.

**IDENTIFY
RESOURCE
IMPACTS
12**

First of three possible actions.

If a previous disturbance is impacting water quality so that objectives are not met, the simulation or measurement will show where the pollution is originating, how much pollution is present, and what kind of pollution is being produced. Using this information, determine which variables within the simulation procedure are causing the pollution. Then refer to section C, table II.2 of this chapter and relate the involved variables to the corresponding resource impacts. (To relate resource impacts to the involved processes, refer to the definitions of the resource impacts in the "Discussion" section of this chapter.)

For an example illustrating this use of the controls procedure, refer to example one in appendix II.A.

**CHOOSE AND APPLY
MITIGATIVE CONTROL
MIXTURE
13**

Using the list of affected variables involved, refer to section B or section C (tables II.3 to II.14) in order to choose controls potentially able to mitigate the impact. The controls procedure is used to prescribe mitigative controls for a previously disturbed site so the proposed silvicultural activity may be accomplished without exceeding the water quality objectives. This procedure should be run several times, thereby arriving at several choices for the manager. For an example illustrating this use of the controls procedure, refer to example one in appendix II.A.

**REVIEW WATER
QUALITY OBJECTIVES
14**

Second of three possible actions.

If existing water quality does not meet the objectives after all feasible mitigative controls have been selected, these objectives should be reviewed and possibly changed by the appropriate authority.

**WATER QUALITY OBJECTIVES
PRECLUDE FURTHER DEGRADATION
15**

Third of three possible actions.

Because the water resource goals or standards are presently being exceeded and the application of mitigative controls cannot correct the problem and objective revision is unacceptable, no silvicultural activity should be considered that would result in any further degradation of the water resource. Alternative land use management of the watershed may be necessary.

**WATER
QUALITY
OBJECTIVES MET
16**

If the existing water quality meets the objectives, a silvicultural activity plan can be formulated.

**DEFINE
PROPOSED SILVICULTURAL
ACTIVITY
17**

Define the silvicultural activity and, depending upon the size and complexity of the activity, such things as a cutting plan, logging plan, transportation plan, fuel management plan, and site preparation may be included in the operational plan.

The control procedure can be used as a reference in the formulation of the initial silvicultural plan. Refer to table II.1 for a list of silvicultural activities and related potential resource impacts. For an example illustrating this use of the controls procedure, refer to example two in appendix II.A.

Preventing pollution is vastly more effective than mitigating problems after they are created. Proper planning and a thorough analysis of the available options will allow the manager to choose the alternatives which best fit the management objectives, while minimizing non-point source pollution potentials and the need for mitigative control.

SIMULATION OF POTENTIAL WATER QUALITY USING ANALYSIS PROCEDURES
18

The potential condition of the water resource, assuming implementation of the proposed silvicultural operation, may be simulated using analysis procedures. Such analysis estimates the potential impacts of the silvicultural operation upon the water resource.

The control procedure can be used in the process of determining what variables are affected by what controls in the simulation process.

WATER QUALITY OBJECTIVES NOT MET
19

The potential water quality following the proposed silvicultural activity is compared with the given water quality objectives. If these objectives are exceeded, the proposed silvicultural activity should be reconsidered.

IDENTIFY RESOURCE IMPACTS
20

First of three possible actions.

If the proposed silvicultural plan is impacting water quality so that objectives are not met, the simulation will show where the pollution is originating, how much pollution is present, and what kind of pollution is being produced. Using this information, determine which variables within the simulation procedure are causing the pollution. Then refer to section C, table II.2 and relate the involved variables to the corresponding resource impacts. (To relate resource impacts to the involved processes, refer to the definitions of the resource impacts in the "Discussion" section of this chapter.)

For an example illustrating this use of the controls procedure, see example three, appendix II.A.

CHOOSE AND APPLY PREVENTIVE CONTROLS
21

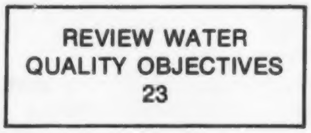
The controls procedure can be used to add new control opportunities to the silvicultural plan if the plan has been shown through simulation to fall short of the objective. Refer to section C (tables II.3 to II.14) and relate the affected variables to potential preventive controls. Preventive controls are preferable over mitigative controls, thus the procedure indicates further simulation with preventive controls before trying mitigative controls.

For an example illustrating this use of the controls procedure, see example three in appendix II.A.

CHOOSE AND APPLY MITIGATIVE CONTROLS
22

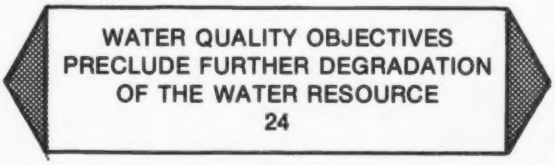
If, after incorporating all feasible preventive controls, the water quality objectives are still exceeded, mitigative controls should be evaluated.

For an example illustrating this use of the controls procedure, refer to example three, appendix II.A.



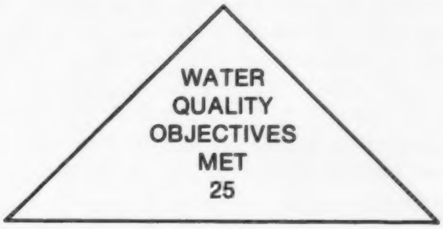
Second of three possible actions.

If, after all feasible preventive and mitigative controls have been applied, the potential water quality resulting from the proposed silvicultural operation exceeds the water quality obejctives, these objectives should be reviewed and possibly changed by the appropriate authority.

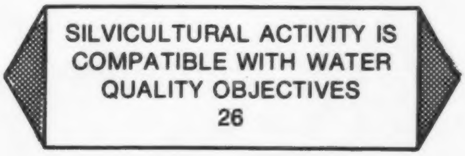


Third of three possible actions.

Because the potential water quality resulting from the implementation of the proposed silvicultural activity might exceed the water resource objectives even after all feasible preventive and mitigative controls have been applied, no silvicultural activity should be considered for the area at present. Alternative land use management of the watershed may be necessary.



The existing water quality is compared with the given water quality objectives. If the existing quality exceeds these objectives, further evaluation is required.



The proposed silvicultural activity is compatible with the water quality objectives and may be implemented insofar as the water resource is concerned.

SECTION A: SILVICULTURAL ACTIVITIES AND POTENTIAL RESOURCE IMPACTS

This section provides a simple table with silvicultural activities listed in one column and the potentially adverse resource impacts resulting from each silvicultural activity listed in the second column (table II.1.). The list of potential impacts associated with particular silvicultural activities is suggested for initial consideration but may need to be revised according to local conditions.

Silvicultural activities listed are:

1. Methods of cutting
2. Felling
3. Yarding methods
4. Road and access system
5. Fuel management methods
6. Site preparation
7. Other activities

Adverse resource impacts include:

1. Aerial drift and application of chemicals
2. Bare soil
3. Channel gradient changes
4. Compaction
5. Debris in channel
6. Excess water
7. Onsite chemical balance changes
8. Slope configuration changes
9. Streamside shading changes
10. Vegetative change
11. Water concentration

Table II.1 can be used in two ways —

1. In the formulation of the silvicultural activity plan.
2. In the process of determining what variables are affected by what controls when running the handbook simulations.

Table II.1.—Silvicultural and related activities and associated potential adverse resource impacts

Activities	**Potential adverse resource impacts**
Methods of cutting:	
Clearcutting Seed tree cutting Selection cutting Shelterwood cutting	Excess water Streamside shading changes Vegetative change
Felling	Debris in channel Vegetative change
Yarding methods:	
Hand pulpwooding	Compaction
Animal skidding Tractor skidding	Bare soil Compaction Water concentration
Cable yarding—high lead	Bare soil Water concentration
Cable yarding—skyline	Bare soil Slope configuration changes
Cable yarding—balloon	Bare soil
Aerial skidding	Onsite chemical balance changes
Mechanized logging (feller, buncher, etc.)	Bare soil Compaction Water concentration

Table II.1—continued

Activities	**Potential adverse resource impacts**
Road and access system:	
Construction and maintenance	Aerial drift and application of chemicals (dust) Bare soil Channel gradient changes Compaction Debris in channel Slope configuration changes Vegetative change
Fuel management methods:	
Burying slash	Bare soil Compaction Slope configuration changes
Firelines and fuel breaks	Bare soil Compaction Slope configuration changes Water concentration
Broadcast burning Hand piling and burning Machine piling and burning Prescribed underburning Jackpot or spot burning	Aerial drift and application of chemicals (ash) Bare soil Compaction Debris in channel Excess water Onsite chemical balance changes Vegetative change Water concentration
Yarding unmerchantable material	Bare soil Compaction Debris in channel
Lop and scatter	Debris in channel
Rolling chopper	Compaction Onsite chemical balance changes Vegetative change
Chip and spread Masticate	Compaction Debris in channel Onsite chemical balance changes
Site preparation:	
Dozer stripping	Bare soil Compaction Excess water Slope configuration changes Vegetative change Water concentration
Terracing	Bare soil Compaction Excess water Slope configuration changes

Table II.1.—Continued

Activities	Potential adverse resource impacts
Machine scalping	Bare soil Compaction
Bedding	Bare soil Water concentration
Plowing Disking	Bare soil Debris in channel Slope configuration changes Vegetative change Water concentration
Drags	Bare soil Compaction Vegetative change Water concentration
Drainage	Bare soil Water concentration
Chemical treatment	Aerial drift and application of chemicals Debris in channel Vegetative change
Other Activities:	
Mechanized planting	Compaction Water concentration
Release from plant competition—Fire	See broadcast burning
Chemical	Aerial drift and application of chemicals
Mechanical	Compaction Water concentration
Thinning and cleaning—	
Hand	Debris in channel Vegetative change
Mechanized	Compaction Debris in channel Vegetative change
Fertilization Seeding with treated seeds	Aerial drift and application of chemicals Onsite chemical balance changes Vegetative change

SECTION B: POTENTIAL RESOURCE IMPACTS AND CONTROL OPPORTUNITIES

This section provides a list of potential adverse resource impacts in alphabetical order followed by a list of suggested controls that may alleviate each particular impact. Control opportunities applicable to all listed resource impacts are presented first. For a description of each control measure, refer to "Section D: Control Opportunity Descriptions" in this chapter.

This section can be used in three ways.

1. In the prescription of mitigative controls for a previously disturbed site. (See example one, appendix II.A).
2. In the formulation of the silvicultural activity plan. (See example two, appendix II.A.).
3. In the prescription of a mixture of preventive and mitigative controls for the alteration of the silvicultural activity plan so it will meet established goals. (See example three, appendix II.A).

Control Opportunities For All Listed Resource Impacts

Conformance to regulations (Procedural)

Enforcement of standards and bonding of operators (Procedural)

Limit disturbed area (Procedural)

Monitoring (Procedural)

Road drainage maintenance during storms (Procedural)

Select low impact equipment (Preventive)

Specify timing (Procedural)

Timely drainage maintenance (Preventive)

Control Opportunities For Aerial Drift And Application Of Chemicals

Chemical application (Preventive)

Control ash or dust buildup (Preventive/mitigative)

Keep pesticides and rodenticides well away from surface runoff (Preventive)

Revegetate treatment areas promptly as local conditions dictate (Mitigative)

Timing of chemical applications (Preventive)

Waterside area (Preventive)

Control Opportunities For Bare Soil

Administrative closure of roads (Procedural/preventive/mitigative)

Appropriate cross-section in roads (Preventive)

Armoring (Preventive/mitigative)

Avoid roading steep slopes (Preventive)

Brush barrier filter at the toe of fill (Preventive/mitigative)

Close roads after use (Procedural/mitigative)

Cut-and-fill slope configuration (Mitigative)

Directional felling (Preventive)

Drainage above cut slope (Preventive/mitigative)

Endline or fly material from waterside areas (Preventive/mitigative)

Fill slope design and locations (Procedural/preventive)

Hold water onsite (Preventive/mitigative)

Identify soil and geologic characteristics and map sensitive areas (Procedural/preventive)

Leave vegetation between strips (Preventive)

Limit equipment operation (Preventive)

Machine or hand plant (Preventive)

Prescribe and execute burns under conditions that will not result in total cleanup (Preventive)

Prescribe limits for the amount of area disturbed by equipment (Preventive)

Prescribe yarding and skidding layout (Preventive)

Prevent fire spread outside treatment areas (Preventive)

Protect road bare surface areas with nonliving material (Mitigative)

Reduce log length (Preventive)

Reduce logging road density (Preventive)

Revegetate treated areas promptly as local conditions dictate (Mitigative)

Slope length (Preventive)

Species selection (Preventive)

Stabilizing structures or cut slopes (Mitigative)

Type of site preparation treatment (Preventive)

Use maximum spacing and minimum strip width in site preparation (Preventive)

Waterside area (Preventive)

Windbreaks or uncut timber to prevent wind erosion (Preventive)

Control Opportunities For Channel Gradient Changes

Armoring (Preventive/mitigative)

Bridges (Preventive)

Ditch checks (Mitigative)

Ditch maintenance (Procedural/mitigative)

Maintain natural water courses (Preventive)

Oversize ditch drain (Preventive)

Reduction of impounded water (Mitigative)

Repair and stabilize damaged areas (Mitigative)

Space culverts to control velocity (Preventive)

Control Opportunities For Compaction

Administrative closure of roads (Procedural/preventive/mitigative)

Close roads after use (Procedural/mitigative)

Directional felling (Preventive)

Endline or fly material from waterside areas (Preventive/mitigative)

Identify soil and geologic characteristics and map sensitive areas (Procedural/preventive)

Leave vegetation between strips (Preventive)

Limit equipment operation (Preventive)

Machine or hand plant (Preventive)

Prescribe limits for the amount of area disturbed by equipment (Preventive)

Prescribe yarding and skidding layout (Preventive)

Reduce logging road density (Preventive)

Reduce vehicle travel (Preventive)

Revegetate treated areas promptly as local conditions dictate (Mitigative)

Rip or scarify compacted surfaces (Mitigative)

Road and landing location (Preventive)

Species selection (Preventive)

Timing of use of off-road, heavy equipment (Preventive)

Type of site preparation treatment (Preventive)

Control Opportunities For Debris In Channel

Bench cut and compact fill (Preventive/mitigative)

Bridges (Preventive)

Brush barrier filter at the toe of fill (Preventive/mitigative)

Directional felling (Preventive)

Eliminate source of debris (Mitigative)

Endline or fly material from waterside areas (Preventive/mitigative)

Fill slope design and location (Procedural/mitigative)

Full bench section (Preventive)

Haul woody material offsite (Mitigative)

Limit equipment operation (Preventive)

Locate activities producing small, woody fragment away from water (Preventive)

Locate corrals away from streams (Animal skidding) (Preventive)

Maintain ground cover (Preventive)

Protect road bare surface areas with nonliving material (Mitigative)

Remove debris from stream (Mitigative)

Repair and stabilize damaged areas (Mitigative)

Revegetate treated areas promptly as local conditions dictate (Mitigative)

Road and landing location (Preventive)

Waterside area (Preventive)

Woody debris disposal sites (Preventive)

Control Opportunities For Excess Water

Cutting block design (Preventive)

Identify soil and geologic characteristics and map sensitive areas (Procedural/preventive)

Machine or hand plant (Preventive)

Maintain ground cover (Preventive)

Outslope firebreak lines and terraces (Preventive)

Prescribe and execute burns under conditions that will not result in total cleanup (Preventive)

Revegetate treated areas promptly as local conditions dictate (Mitigative)

Species selection (Preventive)

Type of site preparation treatment (Preventive)

Use maximum spacing and minimum strip width in site preparation (Preventive)

Waterside area (Preventive)

Control Opportunities For Onsite Chemical Balance Changes

Chemical application (Preventive)

Control ash or dust buildup (Preventive/mitigative)

Haul woody material offsite (Mitigative)

Identify soil and geologic characteristics and map sensitive areas (Procedural/preventive)

Keep pesticides and rodenticides well away from surface runoff (Preventive)

Locate corrals away from streams (Animal skidding) (Preventive)

Machine or hand plant (Preventive)

Pile material in patterns (Preventive)

Protect fuel storage areas (Preventive)

Revegetate treated areas promptly as local conditions dictate (Mitigative)

Species selection (Preventive)

Type of site preparation treatment (Preventive)

Woody debris disposal sites (Preventive)

Control Opportunities For Slope Configuration Changes

Appropriate cross-section for roads (Preventive)

Avoid roading of steep slopes (Preventive)

Bench cut and compact fill (Preventive/mitigative)

Break gradient of firelines (Preventive/mitigative)

Divert water onto stable areas (Preventive)

Drainage above cut slope (Preventive/mitigative)

Full bench section (Preventive)

Identify soil and geologic characteristics and map sensitive areas (Procedural/preventive)

Limit equipment operation (Preventive)

Machine or hand plant (Preventive)

Maintain ground cover (Preventive)

Prescribe yarding and skidding layout (Preventive)

Reduce logging road density (Preventive)

Reduction of impounded water (Mitigative)

Revegetate treated areas promptly as local conditions dictate (Mitigative)

Road and landing location (Preventive)

Species selection (Preventive)

Stabilizing structures on cut slopes (Mitigative)

Type site preparation treatment (Preventive)

Control Opportunities For Streamside Shading Changes

Cutting block design (Preventive)

Directional felling (Preventive)

Revegetate treated areas promptly as local conditions dictate (Mitigative)

Waterside area (Preventive)

Control Opportunities For Vegetative Change

Cutting block design (Preventive)

Directional felling (Preventive)

Leave vegetation between strips (Preventive)

Machine or hand plant (Preventive)

Maintain ground cover (Preventive)

Prescribe limits for the amount of area disturbed by equipment (Preventive)

Revegetate treated areas promptly as local conditions dictate (Mitigative)

Species selection (Preventive)

Timing of chemical application (Preventive)

Type of site preparation treatment (Preventive)

Control Opportunities For Water Concentration

Administrative closure of roads (Procedural/preventive/mitigative)

Armoring (Preventive/mitigative)

Avoid roading of steep slopes (Preventive)

Break gradient of firelines (Preventive/mitigative)

Close roads after use (Procedural/mitigative)

Curbs and berms (Preventive/mitigative)

Cut-and-fill slope configuration (Mitigative)

Cutting block design (Preventive)

Ditch checks (Mitigative)

Ditch maintenance (Procedural/mitigative)

Divert water onto stable areas (Preventive)

Drainage above cut slopes (Preventive/mitigative)

Hold water onsite (Preventive/mitigative)

Identify soil and geologic characteristics and map sensitive areas (Procedural/preventive)

Leave vegetation between strips (Preventive)

Limit equipment operation (Preventive)

Machine or hand plant (Preventive)

Maintain natural water courses (Preventive)

Minimize convergence of firelines (Preventive)

Outslope firebreak lines and terraces (Preventive)

Oversize ditch drain (Preventive)

Pile material in patterns (Preventive)

Prescribe limits for the amount of area disturbed by equipment (Preventive)

Prescribe yarding and skidding layout (Preventive)

Reduce road grades (Preventive)

Reduce vehicle travel (Preventive)

Reduction of impounded water (Mitigative)

Remove debris from stream (Mitigative)

Repair and stabilize damaged areas (Mitigative)

Revegetate treated areas promptly as local conditions dictate (Mitigative)

Rip or scarify compacted surfaces (Mitigative)

Road and landing location (Preventive)

Road ditch (Preventive/mitigative)

Sediment trap (Mitigative)

Slope length (Preventive)

Space culverts to control road ditch erosion (Preventive)

Species selection (Preventive)

Timing of use of off-road, heavy equipment (Preventive)

Trash racks (Preventive)

Type of site preparation treatment (Preventive)

Use maximum spacing and minimum strip width in site preparation (Preventive)

Waterside area (Preventive)

SECTION C: CONTROL OPPORTUNITIES AND SIMULATION VARIABLES

The matrices (tables II.2 to II.14) in this section are the cross-reference system between the "control opportunities" and the handbook simulation procedure (chapters III through XI).

This section lists all variables used in the handbook simulation procedure along the horizontal axis of the matrices. Some of these variables change only with a change in location or area, for example, the R or rainfall factor in the Modified Soil Loss Equation. Other variables are measured values like bedload sediment in the total sediment procedure. The remaining variables (the ones of concern in this chapter) can be affected, either positively or negatively, by certain controls.

All controls, therefore, are listed along the vertical axis of the matrices (tables II.3 to II.14). The controls are listed under each resource impact they are associated with. The "X" symbols on the tables indicate which controls affect which variables. These "X's" are placed with reference to the way the variable is being used in the simulation procedures. For example, the variable "Type and location of the cut" has a specific definition. The use of this variable is to identify the hydrologic processes (i.e., evapotransporation and snowpack changes) as they affect streamflow and not the related effects on silvicultural activity such as site preparation.

The names of the controls and the "X's" on the tables are designed to represent most major relationships and, therefore, some specific controls and their relationships to variables may not be covered.

Table II.2 is a summary showing which simulation variables are affected by which resource impacts. The other 12 tables show which simulation variables are affected by which controls. Table II.3 shows control opportunities for all resource impacts. These controls should be considered in any silvicultural activity plan.

NOTE: In the process of selecting a mixture of controls to mitigate or prevent a specific resource impact, the effects of the selected controls on other areas of concern must be realized. For example, if, through simulation, a problem is noted with surface erosion related to road surfaces, the control lists under "Bare Soil," "Compaction," and "Water Concentration" would be referred to. A control frequently used to prevent water flow across road surfaces is "Drainage Above Cut Slope." But, in addition to preventing surface flow, it also affects slope configuration which indicates that drainage ditches above the cut slope could cause soil mass movement problems.

Table II.2—Potential resource impacts and the variables within the simulation procedure affected by those impacts

Resource impacts	Chapter references to the simulation procedure and affected variables																														
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Aerial drift and application of chemicals												x	x																		
Bare soil				x								x	x		x							x					x				
Channel gradient change																					x										
Compaction											x	x			x																
Debris in channel																				x	x										
Excess water				x											x					x											
Onsite chemical balance changes																															
Slope configuration change										x						x			x		x			x	x	x					
Stream shading change																											x				
Vegetative change	x			x								x	x		x												x				
Water concentration				x											x					x											

[1] Measured value.
[2] Changes only with location.
[3] See "Surface Erosion," chapter IV
[4] See "Hydrology," chapter III
[5] See "Soil Mass Movement," chapter V
[6] Can be taken from chapter III or measured directly.
[7] Calculated value.

Table II.2—continued

Resource impacts	Chapter references to the simulation procedure and affected variables																				
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[3]	Fines-mass movement[5]	Coarse material-mass movement[5]	Median size material-mass movement[5]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic-slope[1]	No specific variables, consider effects upon each total subject		
Aerial drift and application of chemicals																				x	x	x
Bare soil																						
Channel gradient change		x										x										
Compaction																						
Debris in channel	x	x										x								x	x	x
Excess water			x																			
Onsite chemical balance changes																				x	x	x
Slope configuration change																						
Stream shading change											x	x										
Vegetative change											x	x										
Water concentration			x																			

Table II.3—Control opportunities for all resource impacts and the variables within the simulation procedure affected by those controls

Control opportunities for all resource impacts	Chapter references to the simulation procedure and affected variables																														
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Conformance to regulations	x	x	x	x						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Enforcement of standards and bonding of operators	x	x	x	x						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Limit disturbed area	x	x	x	x						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Monitoring	x	x	x	x						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Road drainage maintenance during storms											x	x	x	x	x		x			x	x	x		x	x		x				
Select low impact equipment		x	x	x						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Specify timing	x	x	x	x					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Timely drainage maintenance				x											x					x	x	x									

[1] Measured value.
[2] Changes only with location.
[3] See "Surface Erosion," chapter IV
[4] See "Hydrology," chapter III
[5] See "Soil Mass Movement," chapter V
[6] Can be taken from chapter III or measured directly.
[7] Calculated value.

Table II.3—continued

	Chapter references to the simulation procedure and affected variables																					
	Total sediment variables (ch. VI)										**Stream temperature variables (ch. VII)**									**Dissolved oxygen & organic matter (ch. IX)**	**Nutrients (ch. X)**	**Introduced chemicals (ch. XI)**
Control opportunities for all resource impacts	Bankful width-depth	Water surface slope	Change in discharge or duration^{4}	Bankful discharge^{7}	Suspended sediment^{1}	Bedload sediment^{1}	Surface erosion sediment^{3}	Fines-mass movement^{8}	Coarse material-mass movement^{5}	Median size material-mass movement^{5}	Vegetative shading	Length-exposed reach	Location-latitude^{1}	Year-day-month^{1}	Stream width^{1}	Discharge^{6}	Bedrock^{1}	Azimuth^{1}	Topographic slope^{1}	**No specific variables consider effects upon each total subject**		
Conformance to regulations	x	x									x	x								x	x	x
Enforcement of standards and bonding of operators	x	x									x	x								x	x	x
Limit disturbed area	x	x									x	x								x	x	x
Monitoring	x	x									x	x								x	x	x
Road drainage maintenance during storms																				x	x	x
Select low impact equipment	x	x									x	x								x	x	x
Specify timing	x	x									x	x									x	x
Timely drainage mantenance	x	x																		x	x	x

Table II.4—Control opportunities for aerial drift and application of chemicals and the variables within the simulation procedure affected by those controls

Control opportunities for aerial drift and application of chemicals	Chapter references to the simulation procedure and affected variables																														
	Hydrology variables (ch. III)								**Surface erosion variables (ch. IV)**											**Ditch erosion (ch. IV) (app. IV-C)**			**Soil mass movement variables (ch. V)**								
	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Chemical application												x	x		x												x				
Control ash or dust buildup																															
Keep pesticides and rodenticides away from surface runoff																															
Revegetate treatment areas promptly												x	x									x					x				
Timing of chemical application												x	x		x												x				
Waterside area				x						x	x	x	x		x		x	x									x				

[1] Measured value.
[2] Changes only with location.
[3] See "Surface Erosion," chapter IV
[4] See "Hydrology," chapter III
[5] See "Soil Mass Movement," chapter V
[6] Can be taken from chapter III or measured directly.
[7] Calculated value.

Table II.4—continued

Control opportunities for aerial drift and application of chemicals	Chapter references to the simulation procedure and affected variables																					
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[3]	Fines-mass movement[5]	Coarse material-mass movement[5]	Median size material-mass movement[5]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	No specific variables consider effects upon each total subject		
Chemical application											x									x	x	x
Control ash or dust buildup																					x	x
Keep pesticides and rodenticides away from surface runoff																				x	x	x
Revegetate treatment areas promptly											x											
Timing of chemical application																				x	x	x
Waterside area											x	x								x	x	x

Table II.5—Control opportunities for bare soil and the variables within the simulation procedure affected by those controls

Control opportunities for bare soil	Chapter references to the simulation procedure and affected variables																													
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Administrative closure of roads											x	x	x																		
Appropriate cross-section for roads			x							x						x		x	x	x				x	x	x					
Armoring												x	x									x									
Avoid roading steep slopes			x							x						x		x	x					x	x	x					
Brush barrier filter at the toe of fill																		x													
Close roads after use											x	x	x														x				
Cut and fill slope configuration			x							x						x		x	x	x					x	x					
Directional felling											x	x	x														x				
Drainage above cut slope			x	x						x					x			x		x	x	x			x	x					
Endline of fly material from waterside area to upslope landing											x	x	x														x				
Fill slope design and location										x	x	x				x		x	x	x				x	x	x					
Hold water onsite				x						x		x			x			x							x						
Identify soil and geologic characteristics and map sensitive areas											x			x									x							x	x
Leave vegetation between site preparation strips				x						x		x	x		x			x									x				
Limit equipment operation											x	x	x				x			x	x										
Machine or hand plant											x	x	x														x				

[1] Measured value.

[2] Changes only with location.

[3] See "Surface Erosion," chapter IV

[4] See "Hydrology," chapter III

Table II.5—continued

Control opportunities for bare soil	Chapter references to the simulation procedure and affected variables																					
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[3]	Fines-mass movement[5]	Coarse material-mass movement[5]	Median size material-mass movement[5]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	No specific variables consider effects upon each total subject		
Administrative closure of roads																						
Appropriate cross-section for roads																						
Armoring																						
Avoid roading steep slopes																						
Brush barrier filter at the toe of fill																				x	x	x
Close roads after use																						
Cut and fill slope configuration																						
Directional felling	x	x									x									x	x	x
Drainage above cut slope																						
Endline of fly material from waterside area to upslope landing											x									x	x	x
Fill slope design and location	x																			x	x	x
Hold water onsite																						
Identify soil and geologic characteristics and map sensitive areas																						
Leave vegetation between site preparation strips																						
Limit equipment operation	x	x																		x	x	x
Machine or hand plant																				x	x	x

[5] See "Soil Mass Movement," chapter V

[6] Can be taken from chapter III or measured directly.

[7] Calculated value.

Table II.5—continued

Control opportunities for bare soil	Chapter references to the simulation procedure and affected variables																														
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Prescribe and execute burns under conditions that will not result in total cleanup												x	x														x				
Prescribe limits for the amount of area disturbed by equipment										x	x	x	x											x	x	x	x				
Prescribe yarding and skidding layout										x	x	x	x		x	x		x	x								x				
Prevent fire spread outside treatment areas												x	x														x				
Protect bare surface areas with non-living material												x	x									x									
Reduce log length										x	x	x						x													
Reduce logging road density			x							x	x	x	x			x		x	x					x	x	x					
Revegetate treated areas promptly as local conditions dictate				x								x	x									x					x				
Slope length										x								x						x							
Species selection										x	x	x	x		x												x				
Stabilizing structures or cut slopes												x	x														x				
Type of site preparation treatment										x	x	x	x		x	x	x	x	x						x	x	x				
Use maximum spacing and minimum strip width in site preparation				x						x		x				x	x	x	x						x		x				
Waterside area				x						x	x	x	x		x		x	x									x				
Wind breaks or uncut timber to prevent wind erosion																															

Table II.5— continued

Control opportunities for bare soil	Chapter references to the simulation procedure and affected variables																					
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[5]	Fines-mass movement[6]	Coarse material-mass movement[6]	Median size material-mass movement[6]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	No specific variables consider effects upon each total subject		
Prescribe and execute burns under conditions that will not result in total cleanup																						
Prescribe limits for the amount of area disturbed by equipment																						
Prescribe yarding and skidding layout																						
Prevent fire spread outside treatment areas																						
Protect bare surface areas with non-living material																						
Reduce log length																						
Reduce logging road density																						
Revegetate treated areas promptly as local conditions dictate											x									x	x	x
Slope length																						
Species selection											x											
Stabilizing structures or cut slopes																						
Type of site preparation treatment																				x	x	x
Use maximum spacing and minimum strip width in site preparation																						
Waterside area											x	x								x	x	x
Wind breaks or uncut timber to prevent wind erosion																				x	x	x

Table II.6—Control opportunities for channel gradient changes and the variables within the simulation procedure affected by those controls

Control opportunities for channel gradient changes	Chapter references to the simulation procedure and affected variables																														
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Armoring												x	x									x									
Bridges																		x		x	x										
Ditch checks																					x	x									
Ditch maintenance																				x	x	x									
Maintain natural water courses																															
Oversize ditch drain																				x											
Reduction of impounded water				x											x					x					x						
Repair and stabilize damaged areas																				x	x	x									
Space culverts to control velocity																				x	x										

[1] Measured value.
[2] Changes only with location.
[3] See "Surface Erosion," chapter IV
[4] See "Hydrology," chapter III
[5] See "Soil Mass Movement," chapter V
[6] Can be taken from chapter III or measured directly.
[7] Calculated value.

Table II.6—continued

	Chapter references to the simulation procedure and affected variables																					
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
Control opportunities for channel gradient changes	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[8]	Fines-mass movement[8]	Coarse material-mass movement[8]	Median size material-mass movement[8]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	No specific variables consider effects upon each total subject		
Armoring	x																					
Bridges	x	x																		x	x	x
Ditch checks		x																				
Ditch maintenance																						
Maintain natural water courses	x	x																				
Oversize ditch drain																						
Reduction or impounded water																						
Repair and stabilize damaged areas	x	x																				
Space culverts to control velocity	x	x																				

Table II.7—Control opportunities for compaction and the variables within the simulation procedure affected by those controls

Control opportunities for compaction	Chapter references to the simulation procedure and affected variables																														
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Administrative closure of roads											x	x	x																		
Close roads after use											x	x	x																		
Directional felling											x	x	x														x				
Endline or fly material from waterside areas to upslope landings											x	x	x														x				
Identify soil and geology characteristics and map sensitive areas											x			x									x							x	x
Leave vegetation between site-preparation strips				x						x		x	x		x			x									x				
Limit equipment operation											x	x	x				x			x	x										
Machine or hand plant											x	x	x														x				
Prescribe limits for the amount of area disturbed by equipment										x	x	x	x				x							x	x	x	x				
Prescribe yarding and skidding layout										x	x	x	x		x	x		x	x								x				
Reduce logging road density				x						x	x	x	x			x		x	x					x	x	x					

[1] Measured value.
[2] Changes only with location.
[3] See "Surface Erosion," chapter IV
[4] See "Hydrology," chapter III
[5] See "Soil Mass Movement," chapter V
[6] Can be taken from chapter III or measured directly.
[7] Calculated value.

Table II.7— continued

Control opportunities for compaction	Chapter references to the simulation procedure and affected variables																					
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
	Bankful width-depth	Water surface slope	Change in discharge or duration[1]	Bankful discharge[1]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[2]	Fines-mass movement[3]	Coarse material-mass movement[3]	Median size material-mass movement[3]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[4]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	No specific variables consider effects upon each total subject		
Administrative closure of roads																						
Close roads after use																						
Directional felling	x	x									x									x	x	x
Endline or fly material from waterside areas to upslope landings											x									x	x	x
Identify soil and geology characteristics and map sensitive areas																						
Leave vegetation between site-preparation strips																						
Limit equipment operation	x	x																		x	x	x
Machine or hand plant											x									x	x	x
Prescribe limits for the amount of area disturbed by equipment																						
Prescribe yarding and skidding layout																						
Reduce logging road density																						

Table II.7—continued

	Chapter references to the simulation procedure and affected variables																													
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
Control opportunities for compaction	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Reduce vehicle travel											x	x	x														x				
Revegetate treated areas promptly as local conditions dictate				x								x	x									x					x				
Rip or scarify compacted areas											x	x	x		x		x								x						
Road and landing location				x						x	x				x	x		x	x	x	x	x		x	x	x	x				
Species selection										x	x	x	x		x												x				
Timing of use of off-road heavy equipment											x					x	x														
Type of site preparation treatment										x	x	x	x		x	x	x	x	x						x	x	x				

Table II.7— continued

Control opportunities for compaction	Chapter references to the simulation procedure and affected variables: Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[3]	Fines-mass movement[5]	Coarse material-mass movement[5]	Median size material-mass movement[5]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	No specific variables consider effects upon each total subject		
Reduce vehicle travel																						
Revegetate treated areas promptly as local conditions dictate											x									x	x	x
Rip or scarify compacted areas																						
Road and landing location	x	x																		x	x	x
Species selection											x											
Timing of use of off-road heavy equipment																						
Type of site preparation treatment																				x	x	x

Table II.8—Control opportunities for debris in channel and the variables within the simulation procedure affected by those controls

Control opportunities for debris in channel	Chapter references to the simulation procedure and affected variables																														
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Bench cut and compact fill			x							x	x					x		x	x	x	x	x		x	x	x	x				
Bridges																		x		x	x										
Brush barrier filter at toe of slope										x																					
Directional felling											x	x	x														x				
Eliminate source of debris											x																				
Endline or fly material from waterside areas to upslope landings											x	x	x														x				
Fill slope design and location										x	x	x				x		x	x	x				x	x	x					
Full bench section			x							x	x	x				x		x	x					x	x	x	x				
Haul woody material offsite											x	x	x							x	x										
Limit equipment operation											x	x	x				x			x	x										
Locate activities producing small woody fragments away from water											x		x							x	x										
Maintain ground cover				x							x	x	x				x										x				
Protect road bare surface area with nonliving material												x	x																		
Remove debris from stream																															

[1] Measured value.
[2] Changes only with location.
[3] See "Surface Erosion," chapter IV
[4] See "Hydrology," chapter III
[5] See "Soil Mass Movement," chapter V
[6] Can be taken from chapter III or measured directly.
[7] Calculated value.

Table II.8—continued

Control opportunities for debris in channel	Chapter references to the simulation procedure and affected variables																					
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[3]	Fines-mass movement[6]	Coarse material-mass movement[6]	Median size material-mass movement[5]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	No specific variables, consider effects upon each total subject		
Bench cut and compact fill																				x	x	x
Bridges	x	x																		x	x	x
Brush barrier filter at toe of slope																				x	x	x
Directional felling	x	x									x									x	x	x
Eliminate source of debris	x	x																		x	x	x
Endline or fly material from waterside areas to upslope landings											x									x	x	x
Fill slope design and location	x																			x	x	x
Full bench section	x	x																		x	x	x
Haul woody material offsite	x	x																		x	x	x
Limit equipment operation	x	x																		x	x	x
Locate activities producing small woody fragments away from water	x	x																		x	x	x
Maintain ground cover																				x	x	x
Protect road bare surface area with nonliving material																				x	x	x
Remove debris from stream	x	x																		x	x	x

Table II.8— continued

	Chapter references to the simulation procedure and affected variables																														
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)												Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
Control opportunities for debris in channel	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual Precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Repair or stabilize damaged areas																				x	x	x									
Revegetate treated areas promptly as local conditions dictate				x								x	x									x					x				
Road and landing location			x							x	x					x		x	x	x	x	x		x	x	x	x				
Waterside area				x						x	x	x	x		x		x	x									x				
Woody debris disposal sites																															

Table II.8— continued

Control opportunities for debris in channel	Chapter references to the simulation procedure and affected variables																					
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[3]	Fines-mass movement[5]	Coarse material-mass movement[5]	Median size material-mass movement[5]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	No specific variables, consider effects upon each total subject		
Repair or stabilize damaged areas	x	x																		x	x	x
Revegetate treated areas promptly as local conditions dictate											x									x	x	x
Road and landing location	x	x																		x	x	x
Waterside area											x	x								x	x	x
Woody debris disposal sites	x	x																		x	x	x

Table II.9—Control opportunities for excess water and the variables within the simulation procedure affected by those controls

Control opportunities for excess water	Chapter references to the simulation procedure and affected variables																														
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Cutting block design	x	x		x					x	x			x		x			x									x				
Identify soil and geology characteristics and map sensitive areas											x			x									x							x	x
Machine or hand plant											x	x	x														x				
Maintain ground cover				x							x	x	x				x										x				
Out slope fire break lines or terraces															x	x		x							x	x	x				
Prescribe and execute burn under conditions that will not result in total clearing												x	x														x				
Revegetate treated areas promptly as local conditions dictate				x								x	x									x					x				
Species selection										x	x	x	x		x												x				
Type of site preparation treatment										x	x	x	x		x	x	x	x	x						x	x	x				
Use maximum spacing and minimum strip width in site preparation									x	x		x	x		x			x							x		x				
Waterside area				x						x	x	x	x		x		x	x									x				

[1] Measured value.
[2] Changes only with location.
[3] See "Surface Erosion," chapter IV
[4] See "Hydrology," chapter III
[5] See "Soil Mass Movement," chapter V
[6] Can be taken from chapter III or measured directly.
[7] Calculated value.

Table II.9—continued

Control opportunities for excess water	Chapter references to the simulation procedure and affected variables																					
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
	Bankful width-depth	Water surface slope	Change in discharge or duration⁴	Bankful discharge⁷	Suspended sediment¹	Bedload sediment¹	Surface erosion sediment⁸	Fines-mass movement⁶	Coarse material-mass movement⁶	Median size material-mass movement⁶	Vegetative shading	Length-exposed reach	Location-latitude¹	Year-day-month¹	Stream width¹	Discharge⁶	Bedrock¹	Azimuth¹	Topographic slope¹	No specific variables consider effects upon each total subject		
Cutting block design											x	x										
Identify soil and geology characteristics and map sensitive areas																						
Machine or hand plant																						
Maintain ground cover																				x	x	x
Out slope fire break lines or terraces																						
Prescribe and execute burn under conditions that will not result in total clearing																						
Revegetate treated areas promptly as local conditions dictate											x									x	x	x
Species selection											x											
Type of site preparation treatment																				x	x	x
Use maximum spacing and minimum strip width in site preparation																						
Waterside area											x	x								x	x	x

Table II.10—Control opportunities for onsite chemical balance changes and the variables within the simulation procedure affected by those controls

Control opportunities for onsite chemical balance changes	Chapter references to the simulation procedure and affected variables																														
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Chemical application												x	x		x												x				
Control ash or dust build-up																															
Haul woody material offsite											x	x	x																		
Identify soil and geology characteristics and map sensitive areas											x			x									x							x	x
Keep pesticides and rodenticides well away from surface runoff																															
Locate corrals away from streams (animal skidding)												x	x				x	x													
Machine or hand plant											x	x	x														x				
Pile material in patterns											x	x	x																		
Protect fuel storage areas																															
Revegetate treated areas promptly as local conditions dictate				x								x	x									x					x				
Species selection										x	x	x	x		x												x				
Type of site preparation treatment										x	x	x	x		x	x	x	x	x						x	x	x				
Woody debris disposal sites											x	x	x																		

[1] Measured value.
[2] Changes only with location.
[3] See "Surface Erosion," chapter IV
[4] See "Hydrology," chapter III
[5] See "Soil Mass Movement," chapter V
[6] Can be taken from chapter III or measured directly.
[7] Calculated value.

Table II.10— continued

	Chapter references to the simulation procedure and affected variables																					
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
Control opportunities for onsite chemical balance changes	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[3]	Fines-mass movement[5]	Coarse material-mass movement[5]	Median size material-mass movement[5]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	No specific variables consider effects upon each total subject		
Chemical application											x									x	x	x
Control ash or dust build-up																				x	x	x
Haul woody material offsite																				x	x	x
Identify soil and geology characteristics and map sensitive areas																						
Keep pesticides and rodenticides well away from surface runoff																				x	x	x
Locate corrals away from streams (animal skidding)																				x	x	x
Machine or hand plant																				x	x	x
Pile material in patterns																				x	x	x
Protect fuel storage areas																				x	x	x
Revegetate treated areas promptly as local conditions dictate											x									x	x	x
Species selection											x									x	x	x
Type of site preparation treatment																				x	x	x
Woody debris disposal sites																				x	x	x

Table II.11—Control opportunities for slope configuration changes and the variables within the simulation procedure affected by those controls

Control opportunities for slope configuration changes	Chapter references to the simulation procedure and affected variables: Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Appropriate cross section for roads			x							x						x		x	x	x	x			x	x	x					
Avoid roading of steep slopes										x						x		x	x					x	x	x					
Bench cut and compact fill			x							x	x					x		x	x	x	x	x		x	x	x	x				
Break gradient of fire lines										x						x		x						x	x	x					
Divert water onto stable areas															x										x						
Drainage above cut slope			x	x					x	x					x			x		x	x	x		x	x						
Full bench section			x							x	x	x				x				x	x	x		x	x	x	x				
Identify soil and geology characteristics and map sensitive areas											x			x									x							x	x
Limit equipment operation											x	x	x				x			x	x										
Machine or hand plant											x	x	x														x				
Maintain ground cover				x							x	x	x				x										x				
Prescribe yarding and skidding layout										x	x	x	x		x	x		x	x								x				
Reduce logging road density										x	x	x	x			x		x	x					x	x	x					
Reduction of impounded water				x											x					x					x						
Revegetate treated areas promptly as local conditions dictate				x								x	x									x					x				
Road and landing location			x							x	x					x		x	x	x	x	x		x	x	x	x				

Table II.11—continued

Control opportunities for slope configuration changes	Chapter references to the simulation procedure and affected variables																					
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[3]	Fines-mass movement[6]	Coarse material-mass movement[6]	Median size material-mass movement[6]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	No specific variables consider effects upon each total subject		
Appropriate cross section for roads																						
Avoid roading of steep slopes																						
Bench cut and compact fill	x	x																		x	x	x
Break gradient of fire lines																						
Divert water onto stable areas																						
Drainage above cut slope																						
Full bench section	x	x																		x	x	x
Identify soil and geology characteristics and map sensitive areas																						
Limit equipment operation	x	x																		x	x	x
Machine or hand plant											x									x	x	x
Maintain ground cover																				x	x	x
Prescribe yarding and skidding layout																						
Reduce logging road density																						
Reduction of impounded water																						
Revegetate treated areas promptly as local conditions dictate											x	x										
Road and landing location	x	x																		x	x	x

Table II.11— continued

Control opportunities for slope configuration changes	Chapter references to the simulation procedure and affected variables																														
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
	Basal area	Type and location of cut	Routing depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual Precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Slope rounding or reduction in slope cut			x							x						x			x					x	x	x	x				
Species selection										x	x	x	x		x												x				
Stabilize structures or cut slopes											x	x	x														x				
Type of site preparation treatment										x	x	x	x		x	x	x	x	x						x	x	x				

[1] Measured value.
[2] Changes only with location.
[3] See "Surface Erosion," chapter IV
[4] See "Hydrology," chapter III
[5] See "Soil Mass Movement," chapter V
[6] Can be taken from chapter III or measured directly.
[7] Calculated value.

Table II.11— continued

Control opportunities for slope configuration changes	Chapter references to the simulation procedure and affected variables																				
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[3]	Fines-mass movement[5]	Coarse material-mass movement[5]	Median size material-mass movement[5]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	No specific variables consider effects upon each total subject		
Slope rounding or reduction in slope cut																						
Species selection											x											
Stabilize structures or cut slopes																						
Type of site preparation treatment																				x	x	x

Table II.12—Control opportunities for stream shading and the variables within the simulation procedure affected by those controls

Control opportunities for streamside shading	Chapter references to the simulation procedure and affected variables																														
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Cutting block design	x	x		x						x		x	x		x			x									x				
Directional felling											x	x	x														x				
Revegetate treated areas promptly as local conditions dictate				x								x	x														x				
Waterside area				x						x	x	x	x		x		x	x									x				

[1] Measured value.
[2] Changes only with location.
[3] See "Surface Erosion," chapter IV
[4] See "Hydrology," chapter III
[5] See "Soil Mass Movement," chapter V
[6] Can be taken from chapter III or measured directly.
[7] Calculated value.

Table II.12 — continued

Control opportunities for streamside shading	Chapter references to the simulation procedure and affected variables																					
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[3]	Fines-mass movement[5]	Coarse material-mass movement[5]	Median size material-mass movement[5]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	No specific variables consider effects upon each total subject		
Cutting block design											x	x										
Directional felling	x	x									x									x	x	x
Revegetate treated areas promptly as local conditions dictate											x									x	x	x
Waterside area											x	x								x	x	x

Table II.13—Control opportunities for vegetation changes and the variables within the simulation procedure affected by those controls

Control opportunities for vegetation changes	Chapter references to the simulation procedure and affected variables																														
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[7]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual Precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Cutting block design	x	x		x						x			x		x			x									x				
Directional felling											x	x	x														x				
Leave vegetation between site preparation strips				x					x	x		x	x		x			x									x				
Machine or hand plant											x	x	x														x				
Maintain ground cover				x							x	x	x				x										x				
Prescribe limits for the amount of area disturbed by equipment										x	x	x	x				x							x	x	x	x				
Species selection										x	x	x	x		x												x				
Timing of chemical applications												x	x		x												x				
Type of site preparation treatment										x	x	x	x		x	x	x	x	x						x	x	x				
Revegetate treated areas promptly as local conditions dictate				x								x	x														x				

[1]Measured value.
[2]Changes only with location.
[3]See "Surface Erosion," chapter IV
[4]See "Hydrology," chapter III
[5]See "Soil Mass Movement," chapter V
[6]Can be taken from chapter III or measured directly.
[7]Calculated value.

Table II.13 — continued

Control opportunities for vegetation changes	Chapter references to the simulation procedure and affected variables																					
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[3]	Fines-mass movement[6]	Coarse material-mass movement[6]	Median size material-mass movement[6]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	No specific variables consider effects upon each total subject		
Cutting block design											x	x										
Directional felling	x	x									x									x	x	x
Leave vegetation between site preparation strips																						
Machine or hand plant											x									x	x	x
Maintain ground cover																				x	x	x
Prescribe limits for the amount of area disturbed by equipment																						
Species selection											x											
Timing of chemical applications																				x	x	x
Type of site preparation treatment																				x	x	x
Revegetate treated areas promptly as local conditions dictate																				x	x	x

Table II.14—Control opportunities for water concentration and the variables within the simulation procedure affected by those controls

Control opportunities for water concentration	Chapter references to the simulation procedure and affected variables																													
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual Precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Administrative closure of roads											x	x	x																		
Armoring												x	x									x									
Avoid roading of steep slopes			x							x						x		x	x					x	x	x					
Break gradient of fire-lines										x						x		x						x	x	x					
Close roads after use											x	x	x														x				
Curbs and berms										x								x						x	x	x					
Cut and fill slope configuration			x							x						x		x	x	x					x	x					
Cutting block design	x	x		x						x			x		x			x									x				
Ditch checks																					x	x									
Ditch maintenance																				x	x	x									
Divert water onto stable areas															x										x						
Drainage above cut slope			x	x						x					x			x		x	x	x		x	x						
Hold water onsite				x						x		x			x			x							x						
Identify soil and geology characteristics and map sensitive areas											x			x									x							x	x
Leave vegetation between strips				x					x	x		x	x		x			x									x				
Limit equipment operation											x	x	x				x			x	x										
Machine or hand plant											x	x	x														x				
Maintain natural water courses				x																											

Table II.14—continued

Control opportunities for water concentration	Chapter references to the simulation procedure and affected variables																					
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[3]	Fines-mass movement[5]	Coarse material-mass movement[5]	Median size material-mass movement[5]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	No specific variables consider effects upon each total subject		
Administrative closure of roads																						
Armoring																						
Avoid roading of steep slopes																						
Break gradient of firelines																						
Close roads after use																						
Curbs and berms																						
Cut and fill slope configuration																						
Cutting block design		x									x	x										
Ditch checks																						
Ditch maintenance																						
Divert water onto stable areas																						
Drainage above cut slope																						
Hold water onsite																						
Identify soil and geology characteristics and map sensitive areas																						
Leave vegetation between strips																						
Limit equipment operation	x	x																		x	x	x
Machine or hand plant											x									x	x	x
Maintain natural water courses	x	x																				

Table II.14—Control opportunities for water concentration and the variables within the simulation procedure affected by those controls

Control opportunities for water concentration	Chapter references to the simulation procedure and affected variables																														
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
	Basal area	Type and location of cut	Rooting depth	Delivery (user judgment)	Latitude[1]	Seasonal precipitation[1]	Width of opening[1]	Normalized hydrograph[1]	R (Rainfall)[2]	LS (Length-slope)	K (Soil erodibility)	VM (Vegetation-management)	Ground cover density	Soil texture	Surface water flux	Slope gradient	Surface roughness	Distance	Slope shape	R (Hydraulic radius)	S (Slope of channel)	N (Friction factor)	Soil depth	Slope gradient	Drainage characteristics	Slope configuration	Vegetative cover	Annual precipitation[1]	Storm intensity & duration[1]	Parent material[1]	Natural landslides[1]
Minimize convergence of firelines															x										x						
Outslope firebreak lines and terraces															x	x		x						x	x	x					
Oversize ditch drain																				x											
Pile material in patterns											x	x	x																		
Prescribed limits for the amount of area disturbed by equipment										x	x	x	x				x							x	x	x	x				
Prescribe yarding and skidding layout										x	x	x	x		x	x		x	x								x				
Reduce road grades										x						x		x	x		x										
Reduce vehicle travel											x	x	x														x				
Reduction of impounded water			x												x										x						
Remove debris from stream																															
Repair and stabilize damaged areas											x									x	x	x									
Revegetate treated areas promptly as local conditions dictate			x									x	x														x				
Rip or scarify compacted surface											x	x	x		x		x								x						
Road and landing location			x							x	x					x		x	x	x	x	x		x	x	x	x				
Road ditch			x	x														x		x	x	x									

Table II.14—Control opportunities for water concentration and the variables within the simulation procedure affected by those controls — continued

Control opportunities for water concentration	Chapter references to the simulation procedure and affected variables																					
	Total sediment variables (ch. VI)										Stream temperature variables (ch. VII)									Dissolved oxygen & organic matter (ch. IX)	Nutrients (ch. X)	Introduced chemicals (ch. XI)
	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[3]	Fines-mass movement[5]	Coarse material-mass movement[5]	Median size material-mass movement[5]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	No specific variables consider effects upon each total subject		
Minimize convergence of firelines																						
Outslope firebreak lines and terraces																						
Oversize ditch drain																						
Pile material in patterns																				x	x	x
Prescribed limits for the amount of area disturbed by equipment																						
Prescribe yarding and skidding layout																						
Reduce road grades																						
Reduce vehicle travel																						
Reduction of impounded water																						
Remove debris from stream	x	x																		x	x	x
Repair and stabilize damaged areas	x	x																		x	x	x
Revegetate treated areas promptly as local conditions dictate																				x	x	x
Rip or scarify compacted surfaces																						
Road and landing location	x	x																		x	x	x
Road ditch																						

Table II.14 — continued

Control opportunities for water concentration	Chapter references to the simulation procedure and affected variables																														
	Hydrology variables (ch. III)								Surface erosion variables (ch. IV)											Ditch erosion (ch. IV) (app. IV-C)			Soil mass movement variables (ch. V)								
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Sediment traps										x					x			x													
Slope length										x						x		x						x							
Space culverts to control velocity																				x	x										
Species selection										x	x	x	x		x												x				
Timing of use of off-road heavy equipment											x						x														
Trash racks																				x	x										
Type of site preparation treatment										x	x	x	x		x	x	x	x	x						x	x	x				
Use maximum spacing and minimum strip width in site preparation										x		x	x		x			x							x		x				
Waterside area				x						x	x	x	x		x		x	x									x				

[1] Measured value.
[2] Changes only with location.
[3] See "Surface Erosion," chapter IV
[4] See "Hydrology," chapter III
[5] See "Soil Mass Movement," chapter V
[6] Can be taken from chapter III or measured directly.
[7] Calculated value.

Table II.14 — continued

Control opportunities for water concentration	**Chapter references to the simulation procedure and affected variables**																					
	Total sediment variables (ch. VI)										**Stream temperature variables (ch. VII)**									**Dissolved oxygen & organic matter (ch. IX)**	**Nutrients (ch. X)**	**Introduced chemicals (ch. XI)**
	Bankful width-depth	Water surface slope	Change in discharge or duration[4]	Bankful discharge[7]	Suspended sediment[1]	Bedload sediment[1]	Surface erosion sediment[3]	Fines-mass movement[5]	Coarse material-mass movement[5]	Median size material-mass movement[5]	Vegetative shading	Length-exposed reach	Location-latitude[1]	Year-day-month[1]	Stream width[1]	Discharge[6]	Bedrock[1]	Azimuth[1]	Topographic slope[1]	**No specific variables consider effects upon each total subject**		
Sediment traps																						
Slope length																						
Space culverts to control velocity	x	x																				
Species selection											x											
Timing of use of off-road heavy equipment																						
Trash racks	x	x																				
Type of site preparation treatment																				x	x	x
Use maximum spacing and minimum strip width in site preparation																						
Waterside area											x	x								x	x	x

SECTION D: CONTROL OPPORTUNITY DESCRIPTIONS

All controls are listed in alphabetical order with a brief description of each control. Some reference sources are listed, but, in general, the following can be contacted for further information regarding the controls.

Engineering Controls
  Engineering, Forest Service
  Soil Conservation Service
  Soil Conservation Districts
  State and county highway departments

Silvicultural Controls
  State and Private Forestry Offices, Forest Service
  Timber Management, Forest Service
  Watershed Management, Forest Service
  Soil Conservation Service
  Soil Conservation Districts

This section can be used in any phase in the process of choosing mixtures of controls.

Administrative Closure of Roads
Procedural/Preventive/Mitigative — Bare Soil, Compaction, Water Concentration

Closing roads to all traffic during wet periods of the year prevents rutting and related concentrated flow in ruts. It also reduces compaction and sediment production on road surfaces.

Appropriate Cross-Section for Roads
Preventive — Bare Soil, Slope Configuration Changes

Consider the erosion potentials from various cross-sections of the road. Choose cross-sections that offer the least impact on the resource.

Design combinations can be chosen from existing typical cross-sections. See State or local highway departments for information. The least erodible section will vary with condition of soils, cross slopes, precipitation, and road locations. Some examples are:

1. Crown with ditch and culverts
2. Crown with ditch and water bars
3. Dips
4. Inslope with culverts
5. Inslope with water bars
6. Outslope
7. Turnpike

Armoring
Preventive/Mitigative — Bare Soil, Channel Gradient Changes, Water Concentration

Armoring protects ditches, channels, and low water crossings or outfalls. In addition, it stabilizes the channel, prevents damage from eddies, reduces erodible material, and reduces maintenance.

Some examples of armoring are: armor ditches, armor cut banks for concentrated flow, armor fill slopes below vertical curve sags, armor culvert inlets, armor tops of cut ditches, armor at cross drainage pipes and ground or channel culvert discharges.

Avoid Roading of Steep Slopes
Preventive — Bare Soil, Slope Configuration Changes, Water Concentration

If alternatives are available, locate roads on flatter slopes. Vary both the grade and alignment to minimize mileage on steeper slopes. Roads should be built to grade on slopes. Such road planning reduces bare soil per mile of road, reduces slope of cut-and-fill slopes, and reduces length of cut-and-fill slopes.

However, it should be noted that increasing road mileage can also increase total sediment production.

Bench Cut and Compact Fill
Preventive/Mitigative — Debris in Channel, Slope Configuration Changes

Cut benches into natural slope and compact fills to reduce mass failure. This method is usually used on cross slopes greater than 30 percent in unstable material. Compaction increases shear strength within fills, reduces length and amount of fill slope material, and reduces the probability of slumps within the fill. Benches reduce chances for mass failure.

Break Gradient of Firelines
Preventive/Mitigative — Slope Configuration Changes

Change gradient of fireline at intervals by angling slightly up or downslope. This will reduce the length of the distributed slope and reduce both water velocity and concentration. Outsloping should also be continued with gradient breaking to prevent water concentration, especially in sensitive areas.

Bridges
Preventive — Channel Gradient Changes, Debris in Channel

Use bridges or large oval or arch over live streams. Streamflow will be restricted less than the flow through culverts. In addition, channel scour will be reduced because outlet velocities from culverts are eliminated.

Standard bridge design methods are available through State highway offices.

Brush Barrier Filter at the Toe of Fill
Preventive/Mitigative — Bare Soil, Debris in Channel

Build a debris barrier of slash at the toe of the fill to trap sediment from roads or landings. Barriers may be covered with filter cloth. Brush barriers are often considered a temporary measure effective only until vegetative cover is established.

Chemical Application
Preventive — Aerial Drift of Chemicals

Select chemicals on the basis of particle size and volatility. Heavier and larger particles drift less. Choose the most accurate application method for the job within economic reason (e.g., helicopter, fixed wing aircraft, or low elevation spraying). Accurate placement of the chemical cuts down on aerial drift of chemicals. Choose the proper size nozzle, correct formulations, and carriers for site specific conditions. Use properly trained and licensed application personnel to reduce the likelihood of accidental spills and increase the probability that chemicals will be mixed and applied properly. Use only EPA-approved chemicals and follow the label instructions.

See also "Conformance to Regulations" and "Timing of Chemical Application."

Close Roads After Uses
Procedural/Mitigative — Bare Soil, Compaction, Water Concentration

Close temporary timber access roads to all traffic when not used for timber needs. This allows the road's surface to stabilize and vegetative cover to become established. Rutting is substantially reduced.

Drainage facilities need to be oversize or removed to prevent destruction during periods of nonuse and reduced maintenance. Drainage maintenance must be kept current. The road surface may be scarified and seeded upon closure.

Conformance to Regulations
Procedural — All Resource Impacts

Follow EPA regulations regarding chemical handling and application. Regulations are designed to reduce application error.

Refer to various EPA handbooks for the most up-to-date regulations.

Control Ash or Dust Buildup
Preventive/Mitigative — Aerial Drift of Chemicals, Onsite Chemical Balance Changes

Avoid ash or dust concentration in areas where wind or chemical seep could deposit materials into waterways.

Slash burning can be done on a dispersed rather than on a concentrated basis. In addition, cuts and fills from roadbuilding or landing construction can be located away from streams and/or stabilized quickly.

Curbs and Berms
Preventive/Mitigative — Water Concentration

Construct asphalt or concrete curbs or earthen berms on roadway above tops of fill slopes to prevent water on road surface from running over fill slope.

See local Forest Service or State or county highway departments for standard drawings. Some examples are: asphalt or concrete curbs on paved roadway and earth dikes on roadway.

Cut-and-Fill Slope Configuration
Mitigative — Bare Soil, Water Concentration

Leave bank surfaces rough or bench them. Such treatment may reduce flow velocity and aid in revegetation.

Information can be obtained from the Forest Service, Soil Conservation Service, or State highway departments. Some examples are: rough cut banks and bench fill or cut banks.

Cutting Block Design
Preventive — Excess Water, Streamside Shading Change, Vegetation Change, Water Concentration

Limit the size of cutting blocks and disperse them to prevent excess water in subsoil and to maintain root strength. This will allow soils under fully vegetated units to be dried through evapotranspiration during growing seasons and the distances from top to bottom of cutting blocks to be reduced.

This application is most effective on areas with fine-textured subsoils (clays) and erodible surface soils (like those derived from decomposed granite); on steep slopes; on clearcut and seed tree cut areas; and on areas with heavy precipitation falling as rain. Specific treatment methods include:

1. Orient cutting blocks with adequate buffer strips.
2. Orient cutting blocks at right angles to slopes.
3. Disperse cutting blocks.
4. Design more but smaller cutting blocks.

Directional Felling
Preventive — Bare Soil, Compaction, Debris in Channel, Streamside Shading Changes, Vegetation Changes, Water Concentration

Use directional felling as a way of concentrating felled trees to increase logging efficiency and to lessen site disturbance. Use direct felling to prevent trees from falling into the water, especially in waterside areas. Also, fell trees that are close to roads or streambanks and that would naturally uproot before the next silvicultural activity; this will reduce potential bank erosion.

Ditch Checks
Mitigative — Channel Gradient Changes, Water Concentration

Construct a series of armored check dams in the road side ditch. This reduces velocity in ditch by reducing effective grade, mitigates cut bank undercutting, and controls grade.

Ditch Maintenance
Procedural/Mitigative — Channel Gradient Changes,
Water Concentration

Clean ditch to original cross-sections and leave grass lining and vegetative cover. This prevents undercutting and degradation of ditch edges and reduces sediment leaving ditch.

Divert Water Onto Stable Areas
Preventive — Slope Configuration Changes, Water Concentration

Avoid diversion of water onto erosive or mass failure-sensitive areas. Water on such areas can increase erosion. Damage can be avoided by locating sensitive areas before an activity is started. Consult soil, hydrologic, and geologic maps to locate sensitive areas.

Drainage Above Cut Slope
Preventive/Mitigative — Bare Soil, Slope Configuration Changes, Water Concentration

Place drainage above cut slope parallel to roadway to intercept overland and some shallow, subsurface flow before it can run over and down the cut slope.

Use engineering design obtainable from Forest Service or State or local highway departments. Design examples are: use of a perforated pipe at top of cut bank and ditch above cut.

Eliminate Source of Debris
Mitigative — Debris in Channel

Seek out and eliminate sources of organic debris pollutant to prevent their continued entry into water. Specific treatments are: burning woody debris, burying woody debris, constructing barriers to keep debris out of channels, hauling debris offsite, rearranging debris, and revegetating.

Endline or Fly Material from Waterside Areas to Upslope Landings
Preventive/Mitigative -- Bare Soil, Compaction, Debris in Channel

Remove organic material, resulting from silvicultural activity, from waterside areas. Facilitate harvest of merchantable material and removal of unused material and slash, within environmental constraints of the area. Equipment used must be capable of pulling or lifting logs from beds to landings. Lifting the leading end of the log or the entire log is desirable. Material that might enter water must be removed.

This method applies in areas where tractor or other ground-lead methods would cause compaction or channelization of riparian soils, or cause pollution of water. Soil conditions may influence the need for this control, which is more critical as slopes steepen.

Enforcement of Standards and Bonding of Operators
Procedural — All Resource Impacts

Consider contracts with specifications for bonding all contractors and permittees using performance criteria. Insure that planned erosion control measures and all other planned controls are actually carried out on the ground.

Enforcement controls, combined with monitoring, can insure protection of water quality according to project plans. Sample contracts are available from State foresters or Forest Service State and Private Forestry offices.

Fill Slope Design and Location
Procedural/Preventive, Mitigative — Bare Soil, Debris in Channel

When constructing roads, do not allow debris to reach stream. Prevent fill slope material from reaching stream by following design, controlling blasting, and controlling length of fill slope during construction. Reduce fill slope length to prevent stream encroachment by toes of fill slopes.

Designs can be obtained from highway departments. Specific treatments include: gabion placement at the fill slope edge and retaining structures at the toe of fill slope.

Full Bench Section
Preventive — Debris in Channel
Slope Configuration Changes

Build roadbed entirely on natural ground in steep areas. Side casts and fill slopes are eliminated.

Dispose of excess material in stable areas. See Forest Service or local highway department for design specifications.

Haul Woody Material Offsite
Mitigative — Debris in Channel,
Onsite Chemical Balance Changes

Haul chips and other small woody material that result from silvicultural activity and that could add chemicals or result in debris in the stream, to offsite disposal areas.

Hold Water Onsite
Preventive/Mitigative — Bare Soil,
Water Concentration

Retaining water in place through restriction of water movement is one key to minimizing pollution. Use control measures that will disperse water and not allow water to concentrate to prevent sediment movement and establishment of bare soil. Keep unnecessary site disturbance at a minimum for all silvicultural activities and use site stabilization techniques before, during, and after completing these activities. Check local sources for acceptable measures to prevent or remedy the unnecessary movement of water.

Identify Soil and Geologic Characteristics and Map Sensitive Areas
Procedural/Preventive — Bare Soil, Compaction, Excess Water, Onsite Chemical Changes, Slope Configuration Changes, Water Concentration

Using soil analysis techniques, determine the soil/moisture relationship of sites where degradation is likely to occur with normal use. Define the limiting percentage of compaction that will be tolerated on a given percentage of the site area. Also, define what percent of the area may be compacted. Before beginning the operation, study surveys of the area to locate sensitive areas. Avoid these sensitive areas during the operation. Such determinations aid in identifying the types of systems that could be used to carry out the silvicultural prescription, aid in selecting proper equipment, and also may reduce the number and cost of mitigative measures.

Useful information may be obtained from compartment examinations, soil surveys, hydrologic surveys, and geologic surveys. This technique is especially effective in areas prone to mass movement.

Keep Pesticides and Rodenticides Well Away From Surface Runoff
Preventive — Aerial Drift of Chemicals,
Onsite Chemical Balance Changes

Exposing chemicals to surface runoff areas can seriously influence both plant and animal communities. Identify potential surface runoff areas and restrict chemical use near these areas. Pesticides are commonly applied in aerial operations and chemical drifting is a major problem. Regulations concerning chemical use, application procedures, and critical on-the-ground problem areas must be understood by licensed personnel before chemical application.

Refer to controls on "Chemical Application," "Conformance to Regulations," and "Timing of Chemical Application."

Leave Vegetation Between Strips
Preventive — Bare Soil, Compaction,
Vegetation Changes, Water Concentration

When using stripping techniques for site preparation, leave some unstripped ground at intervals; this forms small filter strips around and within the stripped areas.

Refer to Forest Service Region 4 handbooks for more information on stripping techniques.

Limit Disturbed Area
Procedural — All Resource Impacts

Limit areas where work activity takes place at any given time. Require that one operational area be stabilized before beginning work on another area. An operational area can be defined in terms of the maximum number of active cut blocks, maximum number of acres without seeding, or maximum miles of road without installation of permanent erosion controls. Active areas should be only large enough to allow most equipment to work concurrently.

This control is especially useful on large projects.

Limit Equipment Operation
Preventive—Bare Soil, Compaction, Debris in Channel, Slope Configuration Changes, Water Concentration

Limit or eliminate operation of heavy equipment on unstable or highly erodible soils. In addition, equipment operation in streams should be minimized. Limit equipment operation by cable methods of logging and by winching (endlining) logs in unstable areas.

This application is most effective on steep grounds where soil masses are unstable and/or where soils are erodible.

Locate Activities Producing Small, Woody Fragments Away From Water
Preventive — Debris in Channel

Keep chipping and mastication operations well away from streams and water courses.

Locate Corrals Away From Streams (Animal Skidding)
Preventive — Debris in Channel, Onsite Chemical Balance Changes

When using animals in logging operations, place corrals well away from stream courses. Animal waste should be kept out of the water. Water may have to be hauled for the animals.

Machine or Hand Plant
Preventive—Bare Soil, Compaction, Excess Water, Onsite Chemical Balance Changes, Slope Configuration Changes, Vegetation Changes, Water Concentration

The method of tree planting, either by machine or hand, often governs the intensity of site preparation treatments. Machine planting usually requires that the site be cleared of logs, limbs, and other larger debris. Debris is not a problem for hand planting as long as crews can walk through it and trees can be planted at the prescribed spacing. If debris is too heavy for hand planting, the situation is often rectified by a light burn which consumes the small material and often does not expose excessive amounts of soil. In some areas, fire will expose unacceptable amounts of bare soil and mechanical removal of debris is the only alternative. Also, mechanical debris removal is needed to reduce fire hazard and for other resource purposes. In many situations machine planting and associated site preparation can be fully acceptable.

Maintain Ground Cover
Preventive — Debris in Channel, Excess Water, Slope Configuration Changes, Vegetation Changes

Maintain as much vegetation, which may include trees, understory, and litter, as is consistent with management objectives; or establish tree regeneration and desirable species of understory vegetation. Evapotranspiration reduces amounts of water in the soil. Mechanical protection strengthens slopes against mass failure.

Vegetation, through physiological use of soil moisture, will dry soil masses and prevent saturation of subsoils. Ground covered by vegetation will be protected from the impact of raindrops during heavy precipitation, thus preventing detachment and downhill transport of soil particles. Vegetation will produce a protective layer of duff. Infiltration will be enhanced and ground surface water flow will be reduced or eliminated. Tree roots and roots of other species reinforce the soil mass.

Maintain Natural Water Courses
Preventive — Channel Gradient Changes, Water Concentration

Keep stream channels free of debris which might deflect or constrict water flow and which could accelerate bank or channel erosion. Keeping streambanks and channels stable in this manner will reduce sediment loads. Road crossings, bridges, culverts, fords, and other stream encroachments should be aligned and constructed to reduce impacts on flow characteristics.

Remove all introduced organic material from the stream course as soon as it is introduced to prevent damming and streambank alteration. Refer to controls on "Directional Felling" and "Waterside Areas." Both are important in maintaining natural water courses.

Minimize Convergence of Firelines
Preventive — Water Concentration

When locating and constructing firelines, avoid downhill convergence. If firelines do not converge, water will be prevented from concentrating severely.

Monitoring
Procedural — All Resource Impacts

Monitor silvicultural and related activities with periodic inspections. Schedule inspections to allow for maintenance prior to periods of heavy runoff. Pay particular attention to drainage facilities. Monitoring by itself is not a control; however, it is a way to make sure other controls are carried out properly. See "Enforcement of Standards and Bonding of Operators."

Outslope Firebreak Lines and Terraces
Preventive — Excess Water, Water Concentration

When constructing firebreak lines or terraces, make certain they are outsloped so water is not concentrated by insloping. Gully erosion can be controlled by outsloping.

Information regarding laying of grade and other design criteria can be obtained from local highway departments or Forest Service Engineering personnel.

Oversize Ditch Drain
Preventive — Channel Gradient Changes, Water Concentration

Install culverts that are larger than necessary for anticipated runoff, thus allowing some debris plugging before water will flow over road.

See Forest Service or State and county highway departments for culvert size requirements. This is particularly effective when roads are closed to users and when maintenance inspections are infrequent.

Pile Material in Patterns
Preventive — Onsite Chemical Balance Changes, Water Concentration

Pile debris from cutting, site preparation, or fuel management in patterns which prevent concentration of water. Gullying can be prevented by avoiding water concentration around piles of material. Avoid diverting water onto sensitive areas.

Prescribe and Execute Burns Under Conditions That Will Not Result in Total Cleanup
Preventive — Bare Soil, Excess Water

Fuel treatment burns should be cool enough to leave unburned and partially burned material on the site. This offers some ground cover protection for the soil. Alter firing patterns to reduce overall burn intensity so less soil is bared. Some fuel treatment goals may have to be revised as a result of this control. Consider special burning techniques such as the jackpot or spot burn.

The Forest Service and its State and Private Forestry offices will have fuel treatment guidelines that describe fire manipulation in detail.

Prescribe Limits for Amount of Area Disturbed by Equipment
Preventive — Bare Soil, Compaction, Vegetation Changes, Water Concentration

Minimize bare soil area necessary to satisfy silvicultural objective. Increase the amount of acres served by roads or landings by planning truck roads, skid roads, and landings at the same time and by maintaining wider spacing between truck roads and skid roads.

Prescribe Yarding and Skidding Layout
Preventive — Slope Configuration Changes, Water Concentration

Design yarding and skidding patterns to radiate downhill. Skid roads oriented this way will spread, rather than collect, water. Thus, water will not be concentrated and its energy for eroding material into bodies of water will be reduced. The water will also have an increased opportunity to infiltrate.

Water concentration caused by skid roads and trails becomes more severe with increased slope and precipitation and decreased soil particle size. Water concentration must also be considered on shallow slopes particularly in the Southern United States.

Prevent Fire Spread Outside Treatment Areas
Preventive — Bare Soil

Take steps before the fuel treatment operation to prevent fire spread outside treatment areas by using firebreaks and having equipment available. If fires are contained, less bare soil is exposed and aerial drift of ash and dust can be reduced.

Protect Fuel Storage Areas
Preventive — Onsite Chemical Balance Changes

Place fuel storage areas in locations well away from streams or water courses and take precautions to impound or divert a possible fuel spill.

Dimensional ditches and impoundments with straw bales to soak up excess fuel can be effective.

Protect Road Bare-Surface Areas With Nonliving Material
Mitigative — Bare Soil, Debris in Channel

Armor bare soil related to roads, especially in specific locations that are not able to be revegetated.

Use appropriate structural thickness designs and pavement design methods. See local Forest Service or county highway department for appropriate design criteria. Examples are:

1. Gravel road surface: high cost although lower than asphalt paving.
2. Asphalt road surface: high cost relative to other treatments.
3. Spot gravel on critical areas of road surface: used on "soft" areas of road.
4. Dust oil applied to road surface: prevents aggregate breakdown, must be used frequently to be effective.
5. Shot crete surface of cut-and-fill slopes: used only when all else fails; cost is high.
6. Jute mats or excelsior pads on cut-and-fill slopes: rarely used singly, usually used in combination with revegetation.

Prescribe limits for the amount of area disturbed by equipment by constructing narrow truck roads and avoiding unnecessary movement of vehicles off established road and landing areas.

Do not make unnecessary roads. Roads should be designed using such techniques as "rolling dips."

Reduce Road Grades
Preventive — Water Concentration

Reducing road grades tends to reduce ditch erosion and road surface erosion by reducing water velocity. However, there is the possibility of increasing road mileage, in order to use flatter grades, to the point where total sediment yield is increased. Refer to road design standards of local highway departments.

Reduce Log Length
Preventive — Bare Soil

Reduce log length prior to yarding, skidding, or hauling to require less turning space in the woods and to allow use of lower standard roads. (The use of smaller vehicles can mean less turning space which, in turn, reduces the amount of disturbed area.)

However, logging efficiency must be considered. The additional cost of bucking tree-length logs into one or more logs in the woods must be compared with the potential disturbance and exposure of bare soil if the logs are not bucked.

Reduce Logging Road Density
Preventive — Bare Soil, Compaction, Slope Configuration Changes

Hold logging road density in areas sensitive to mass failure to a minimum. If critical areas must be crossed, use bridge, complete fill techniques, or center balance slope methods.

Note that reduction of roads could require a more expensive logging systsem.

Reduce Vehicular Travel
Preventive — Compaction, Water Concentration

Since ruts and compacted tracks can cause water concentration, a simple reduction of vehicular travel to only that which is absolutely necessary would help alleviate water concentration impacts.

Reduction of Impounded Water
Mitigative — Channel Gradient Changes, Slope Configuration Changes, Water Concentration

Divert water from impoundment to prevent excess water from accumulating and increasing the surface erosion and mass failure risk. Drain impounded water away and spread water over more absorbent surfaces. Increase the absorption rate of the impoundment, if possible, by ripping, scarifying, roughening the surface, or establishing vegetative cover. In addition, during or after the operation, prevent debris dam or barrier formation that could lead to water concentration. Locate and remove small dams before problems become large and costs go up.

Specific examples include:

1. Install a ditch drain culvert that discharges onto undisturbed natural ground above and as near to streams as possible.
2. Drain project prior to seasonal shutdown. Ditch, crown, water bar, and remove temporary fills and culverts.
3. Keep project drained during construction; construct ditches, temporary culverts, etc.

Remove Debris From Stream
Mitigative — Debris in Channel, Water Concentration

Remove organic and inorganic debris which has entered the stream from silvicultural and related activities. This reduces pollution from debris and prevents undercutting of slopes.

Debris removal should utilize least damaging methods. Specific treatments include:

1. **Hazard debris removal**
2. **Lining out debris**
3. **Lifting out with loader**
4. **Lifting out with helicopter**
5. **Scattered, free floating debris (chips, slack, fragments) can be gathered by towed or stationary booms or partially submerged screens.**

Repair and Stabilize Damaged Areas
Mitigative — Channel Gradient Changes, Debris in Channel, Water Concentration

Shape and stabilize areas damaged during the operation with organic or inorganic material using outsloping techniques to prevent water concentration. Restore streambanks and stream bottoms to as near original configuration as possible. Prevent continued deterioration of the aquatic environment. Use combinations of soil replacement, placement of gabions, and riprap.

A field decision will have to be made regarding whether or not the repair effort would cause more damage than that existing before repairs were undertaken. Forest Service, Soil Conservation Service, or county agents can offer design advice.

Revegetate Treated Areas Promptly As Local Conditions Dictate
Mitigative — Aerial Drift of Chemicals, Bare Soil, Compaction, Debris in Channel, Excess Water, Onsite Chemical Balance Changes, Slope Configuration Changes, Streamside Shading Changes, Water Concentration

Revegetate using artificial techniques to establish a plant cover on bare soil surfaces — usually skid trails, ditches, and other disturbed areas. Stabilize the soil surface. Revegetation can also increase shading on water. Apply grass, shrub, tree seed, or sod and/or seedlings to exposed areas; add fertilizer, lime, mulch, or jute mats as local conditions dictate. This will reduce soil eroding energy from water related sources.

See Soil Conservation Service, Forest Service, or extension agent for local grass species and requirements for fertilizer, lime, mulch, etc. Grass cover can be very difficult to establish on arid or sterile soils or on fill slopes over 1:1. Jute mats or excelsior pads are often required to hold seed to establish grass in critical areas.

Rip or Scarify Compacted Surfaces
Mitigative — Compaction, Water Concentration

Ripping or scarifying may restore the site's natural water-holding capacity, restore water infiltration capability, increase root permeability, and increase the site's potential to reestablish a vegetative cover. On trails compacted by off-road, heavy equipment, the compacted layer can be remedied by single ripping when layer width is less than two times the depth of compaction. On landings and concentrated use areas where compaction has occurred, the site should be ripped to the depth of compacting. On skid trails, roads, and landings with surface compaction of 8 inches or less, scarification can mitigate some damage.

Need for treatment is determined by examination and testing proctor curves.

Road and Landing Location
Preventive — Compaction, Debris in Channel, Slope Configuration Changes, Water Concentration

Avoid unstable areas and critical slope configuration. Prevent water from accumulating, channeling, eroding, and degrading water and site quality. Keep logging roads and skid trails out of stream bottomlands. Avoid sustained grades; attempt to vary the grade. Whenever possible, locate water concentrating activities on high ground.

Require that hydrologic and soils information be put into an area logging plan. Develop a transportation plan that serves all of the resources with the least total impact by reducing duplication of roads. Specific considerations are:

1. Avoid known slump/slide areas.
2. Avoid areas with high risk of mass failure.
3. Avoid concave slopes in close proximity to streams.
4. Place roads on convex slopes above streams.

Road Ditch
Preventive/Mitigative — Water Concentration

Drain inside road ditch with pipe or water bar.

This is a positive method of controlling surface routing across a road. A plugged ditch may cause mass failure and accelerated road surface erosion. Therefore, maintenance is necessary.

Road Drainage
Preventive — Compaction, Excess Water, Slope Configuration Changes, Water Concentration

Divert road runoff at frequent intervals to reduce volume and velocity, thereby reducing erosion potential and providing the opportunity for water to infiltrate soil before reaching stream. Road drainage and spreading techniques include dipping of sustained grades, outsloping and/or insloping and cross draining of water onto areas most capable of spreading and infiltrating the runoff. This control could pertain to tractor trails, roads, and landings. Additional treatments are lead off ditches and water bars. For design specifications, consult Forest Service regional road manuals and related publications.

Road Drainage Maintenance During Storms
Preventive — All Resource Impacts

Patrol roads when heavy precipitation is forecast and during precipitation. Keep drainage system functioning during runoff (unplug culverts, remove slides from ditches, etc.). Storm patrol organization and procedures must be established before the storm occurs. Labor and equipment must be available for emergency work. Storm forecasting is required.

Storm patrol is particularly useful in areas of frequent, very heavy rainfall with steep slopes and unstable material.

Sediment Trap
Mitigative — Water Concentration

Excavate or dam a sediment pond below culverts. This sediment trap provides a pond of water below the culvert, thus allowing sediment to settle out.

See Forest Service or State or local highway department for design characteristics. Application is very site specific. This is a short-term control which is usually effective only until vegetative cover has become established. Pond will eventually silt full.

Select Low Impact Equipment
Preventive — All Resource Impacts

Determine what type of equipment can minimize compaction and accomplish the required work. Make determinations of the equipment's pulling capacity, pounds/square inch of float, speed, and stability.

May require equipment other than what is presently used in the area or a change to a different system that meets the resource objective (i.e., tractor to cable).

Slope Length
Preventive — Bare Soil, Water Concentration

Avoid silvicultural treatments using long downslope distances to prevent high overland water velocities and decrease erosion.

The Forest Service has standard placement tables for critical distances.

Space Culverts to Control Road Ditch Erosion
Preventive — Channel Gradient Changes,
Water Concentration

Space ditch drain culverts to control quantity and velocity of water flowing in roadside ditches. Proper drainage regulates water quantity and velocity, soil detachment, and transport.

See Forest Service or state highway departments for standards. Additional ditch drain culverts may help to control active ditch erosion.

Species Selection
Preventive — Bare Soil, Compaction, Excess Water,
Onsite Chemical Balance Changes,
Slope Configuration Changes, Vegetation Changes,
Water Concentration

The tree species to be planted often govern the type and the intensity of site preparation treatments. Tree seedlings have varying tolerance to plant competition. As a general rule, tolerant species require less intensive treatments, while intolerant species require more intensive treatments.

Specify Timing
Procedural — All Resource Impacts

Specify timing of control application and/or work phases that are critical to quality control. Timing should be specified in terms of both calendar and spatial relationships. Such timing specification should be used for vegetative establishment, culvert and bridge installation, earth work, establishment of size, number, and placement of active areas, and the scheduling of activity on these areas.

Stabilizing Structures on Cut Slopes
Mitigative — Bare Soil,
Slope Configuration Changes

A variety of engineering structures may be installed where the toes of unstable slopes have been truncated by bank cutting in streams, road cuts, skid roads, or firelines. Cut banks and/or fill slopes at the toes of slopes can be counterbalanced with rock to stop mass soil wasting at toes of unstable slopes and potential upslope mass failure. Specific treatments include: Steel cribbing structures, gabions, corrugated pipe, and rock.

Timely Drainage Maintenance
Preventive — All Resource Impacts

Keep maintenance current, particularly off drainage facilities. Insure that drainage facilities are functioning properly at all times, especially prior to periods of heavy runoff.

Much of the drainage maintenance work can be done by personnel other than maintenance crews. Quite often the only "equipment" needed is a shovel.

Timing of Chemical Application
Preventive — Aerial Drift of Chemicals, Vegetation Changes

Apply chemicals during calm, dry weather (mornings and evenings). Little drift is encountered if chemicals are applied during calm weather. Rainstorms can wash freshly applied chemicals into water. Avoid high runoff periods when applying chemicals. Refer to "Chemical Applications" control for further considerations.

Timing of Use of Off-Road, Heavy Equipment
Preventive — Compaction, Water Concentration

Analyze soil to determine its characteristics and define the soil moisture limits for using heavy equipment. Limit use of heavy equipment when soil moisture is high and thus reduce chances of soil compaction. Include timing constraints in contracts if applicable.

Trash Racks
Preventive — Water Concentration

Locate trash racks at, or upstream from, culvert entrances to catch debris before it plugs culverts. This can reduce bank cutting around culvert entrances caused by plugging and reduces the chance for water to overflow roads during high water. Note, however, that with great amounts of debris, trash racks are not effective; they may actually make the problem worse. Numerous standard drawings exist. See Forest Service or State highway department.

Type of Site Preparation Treatment
Preventive — Bare Soil, Compaction, Excess Water, Onsite Chemical Balance Changes, Vegetative Changes, Slope Configuration Changes, Water Concentration

Site preparation is used to create a favorable environment for tree establishment and to secure acceptable tree survival and stocking. There is a broad range of site preparation treatments with a wide range of potential impacts. The treatment chosen for a given site is governed by the site's physical and residual stand characteristics, the tree species to be planted, whether the trees can be machine or hand planted, and whether regeneration will be by seedlings or seed. Site preparation uses hand and mechanical methods, herbicides, and fire, or combinations of these treatments.

The principle here is that many characteristics will govern what site preparation treatments are used. Several possible treatments can be applied to a given site; the one chosen depends upon the management goals for that site.

Refer to Dissmeyer and Singer (1977) and Balmer and others (1976) for more complete information.

Use Wind Breaks or Uncut Timber to Prevent Wind Erosion
Preventive — Bare Soil

Leave wind breaks or uncut timber around silvicultural and related activities in wind erosion areas. These can slow or disrupt wind currents which could cause erosion. Disrupted wind currents will drop suspended soil particles.

Use Maximum Spacing and Minimum Strip Width in Site Preparation
Preventive — Bare Soil, Excess Water, Water Concentration

Leave undisturbed vegetation or ground cover between site preparation strips. Leave the maximum width possible to meet silvicultural prescriptions. Continuous blocks of bare soil will be broken up, thus preventing water concentration and surface soil loss.

Waterside Area
Preventive — Aerial Drift of Chemicals, Bare Soil, Debris in Channel, Excess Water, Streamside Shading Changes, Water Concentration

Waterside areas are strips of vegetated land where treatment is carefully controlled. Such zones are often located between cut, site-prepared, burned, fertilized, herbicided, and pesticided areas, roads, and streams. Vegetation in the waterside area reduces amounts of debris, surface runoff, erosion, and chemicals reaching the stream while reducing the impact of some management activities on water temperatures. Use mapping and on-the-ground reconnaissance to identify aquatic areas which, because of direction of flow, shoreline arrangement, exposure, wind patterns, and related phenomena, are susceptible to temperature changes. Modify silvicultural prescriptions accordingly.

Provide shade on treated areas and in strategic locations near riparian zones and water surfaces to disrupt radiation patterns and slow air movement into sensitive areas. Maintain temperature regimes of the aquatic environment. Leave as much native vegetation on treated areas as possible. Avoid "total cleanup" of debris. Protect vegetation in riparian areas and leave substantial windfirm trees in areas where they will obstruct radiation onto riparian zones and onto water, particularly in the shallows.

Refer to the "Directional Felling" control for harvesting timber in waterside areas. The Forest Service's State and Private Forestry group has information on proper layout and design of waterside areas.

Woody Debris Disposal Sites
Preventive — Debris in Channel,
Onsite Chemical Balance Changes

Do not pile woody material or ash where it could wash into streams. Chemical seep from wood should not be allowed to reach water bodies.

Downstream culverts and trash racks will need less maintenance and organic matter will be prevented from changing the chemical balance in streams. Very little is known about water pollution caused by chemical leaching from wood.

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APPENDIX II.A: EXAMPLES ILLUSTRATING VARIOUS USES OF THE CONTROL OPPORTUNITIES

EXAMPLE ONE — MITIGATIVE CONTROLS FOR A PREVIOUSLY DISTURBED SITE

Example one procedure. — This example illustrates the use of the controls procedure to prescribe mitigative controls for a previously disturbed site (disturbed by man) so that silvicultural activity can be accomplished without exceeding water quality objectives. (Fig. II.A.1 illustrates this application of the procedure.)

This procedure should be run several times, thereby arriving at several choices for the manager.

1. Simulate, using handbook procedures, or measure watershed condition before silvicultural planning begins.
2. If a previous disturbance (a road, a landing, etc.) is impacting water quality so that objectives are not met, the simulation will show where the pollution is originating, how much pollution there is, and what kind of pollution is being produced. Using this information, determine which variables within the simulation procedure are causing the pollution. Then refer to table II.2 and relate the involved variables to the corresponding resource impacts (bare soil, compaction, etc.). (To relate the resource impacts to the involved processes — increased runoff, reduced infiltration, etc. — refer to the definitions of the resource impacts in the "Discussion" section of this chapter.)
3. Once the resource impacts are identified, refer to section B or section C, tables II.3 to II.14 of this chapter for a list of controls that could mitigate the resource impacts. At this point, a mix of such controls is selected.
4. Then use section D for a description of the selected controls. Reference sources are listed in section D for those controls needing an expanded, technical definition.
5. Use section C to cross-reference the control opportunities with the variables and procedures used in the handbook simulation.
6. Simulate (using handbook procedures) the potential outcome of using the new mixture of mitigative controls to meet the water quality objectives.
7. If the water quality objectives are not met, new mixes of mitigative controls will have to be chosen and simulated again using the handbook procedures.

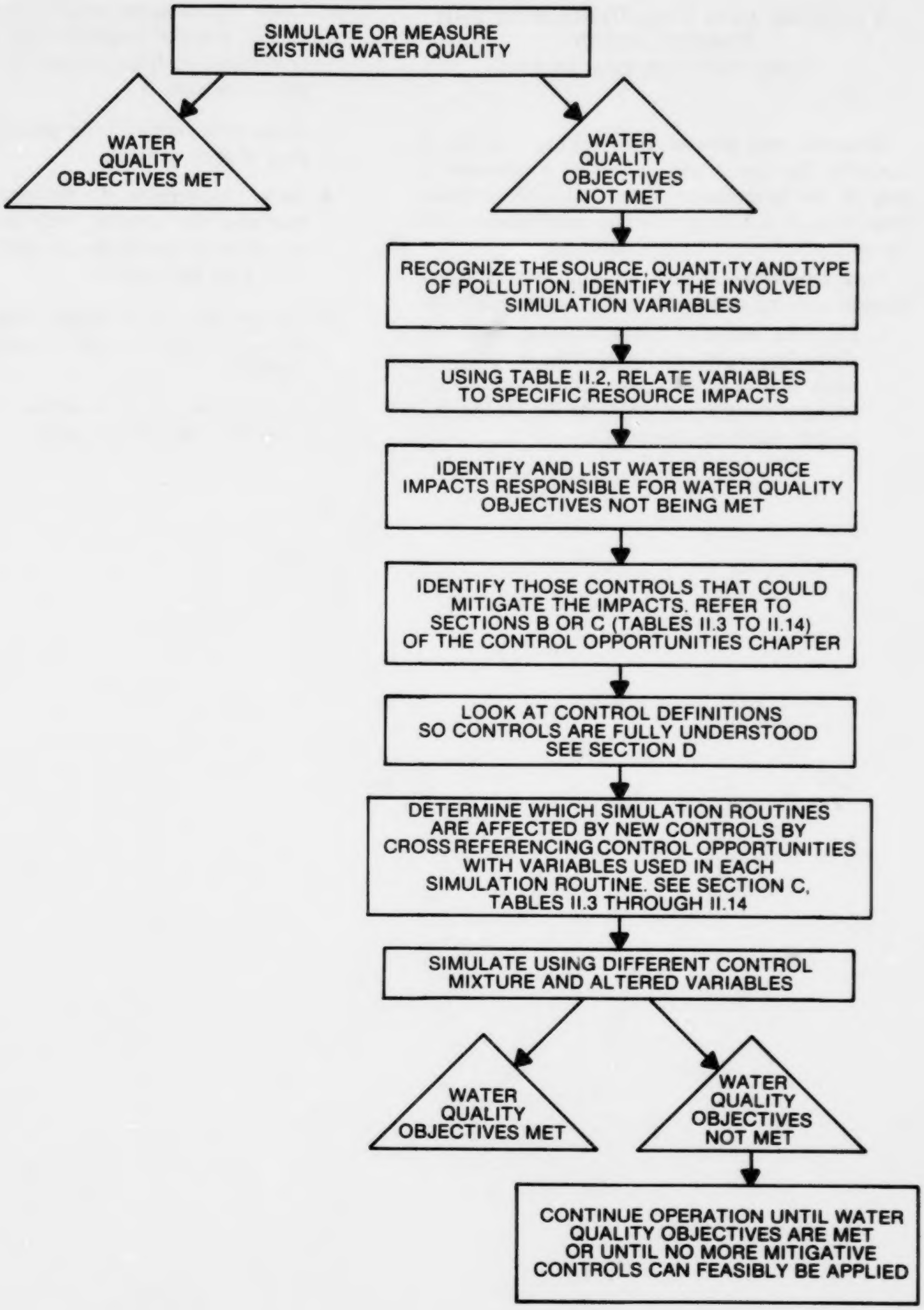
SIMULATE OR MEASURE EXISTING WATER QUALITY
WATER QUALITY OBJECTIVES MET
WATER QUALITY OBJECTIVES NOT MET
RECOGNIZE THE SOURCE, QUANTITY AND TYPE OF POLLUTION. IDENTIFY THE INVOLVED SIMULATION VARIABLES
USING TABLE II.2, RELATE VARIABLES TO SPECIFIC RESOURCE IMPACTS
IDENTIFY AND LIST WATER RESOURCE IMPACTS RESPONSIBLE FOR WATER QUALITY OBJECTIVES NOT BEING MET
IDENTIFY THOSE CONTROLS THAT COULD MITIGATE THE IMPACTS. REFER TO SECTIONS B OR C (TABLES II.3 TO II.14) OF THE CONTROL OPPORTUNITIES CHAPTER
LOOK AT CONTROL DEFINITIONS SO CONTROLS ARE FULLY UNDERSTOOD SEE SECTION D
DETERMINE WHICH SIMULATION ROUTINES ARE AFFECTED BY NEW CONTROLS BY CROSS REFERENCING CONTROL OPPORTUNITIES WITH VARIABLES USED IN EACH SIMULATION ROUTINE. SEE SECTION C, TABLES II.3 THROUGH II.14
SIMULATE USING DIFFERENT CONTROL MIXTURE AND ALTERED VARIABLES
WATER QUALITY OBJECTIVES MET
WATER QUALITY OBJECTIVES NOT MET
CONTINUE OPERATION UNTIL WATER QUALITY OBJECTIVES ARE MET OR UNTIL NO MORE MITIGATIVE CONTROLS CAN FEASIBLY BE APPLIED

Figure II.A.1—Example one procedure.

EXAMPLE TWO — CONTROLS IN THE FORMULATION OF SILVICULTURAL PLANS

Example two procedure. — This example illustrates the use of the control as a reference to help in the formulation of the initial silvicultural plan. (Fig. II.A.2 illustrates this application of the procedure.)

This procedure should be run several times, thereby arriving at several choices for the manager.

1. List the resource impacts associated with silvicultural activity by referring to section A, table II.1, of this chapter. For example, bare soil and compaction might be associated with tractor skidding operations.
2. Once the resource impact has been determined, a list of controls which could prevent or mitigate each impact can be made by referring to section B.
3. Then go to section D for an expanded definition of each control.
4. Refer to section C for cross-correlation between the control and the variable or variables it affects for simulation of possible effects on the stream.
5. Narrow the control list to those controls most effective in preventing or mitigating resource impacts.
6. Include the most effective controls in the proposed silvicultural plan.

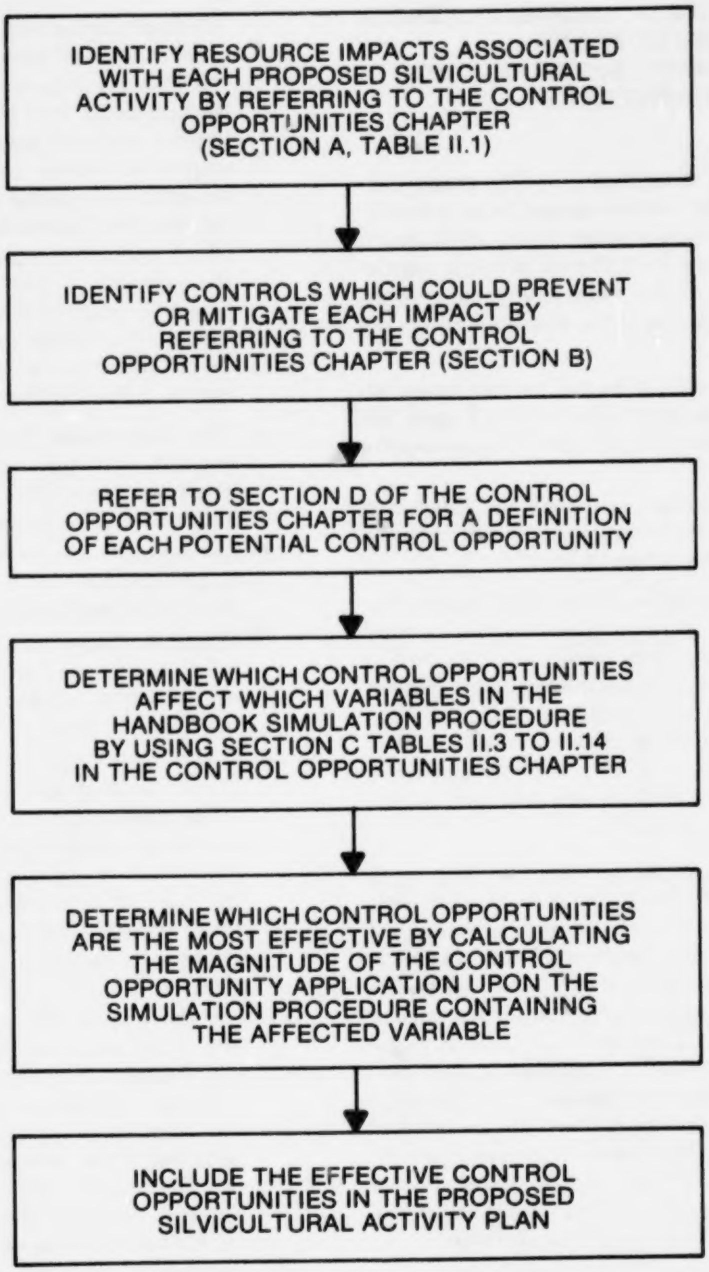
IDENTIFY RESOURCE IMPACTS ASSOCIATED WITH EACH PROPOSED SILVICULTURAL ACTIVITY BY REFERRING TO THE CONTROL OPPORTUNITIES CHAPTER (SECTION A, TABLE II.1)
IDENTIFY CONTROLS WHICH COULD PREVENT OR MITIGATE EACH IMPACT BY REFERRING TO THE CONTROL OPPORTUNITIES CHAPTER (SECTION B)
REFER TO SECTION D OF THE CONTROL OPPORTUNITIES CHAPTER FOR A DEFINITION OF EACH POTENTIAL CONTROL OPPORTUNITY
DETERMINE WHICH CONTROL OPPORTUNITIES AFFECT WHICH VARIABLES IN THE HANDBOOK SIMULATION PROCEDURE BY USING SECTION C TABLES II.3 TO II.14 IN THE CONTROL OPPORTUNITIES CHAPTER
DETERMINE WHICH CONTROL OPPORTUNITIES ARE THE MOST EFFECTIVE BY CALCULATING THE MAGNITUDE OF THE CONTROL OPPORTUNITY APPLICATION UPON THE SIMULATION PROCEDURE CONTAINING THE AFFECTED VARIABLE
INCLUDE THE EFFECTIVE CONTROL OPPORTUNITIES IN THE PROPOSED SILVICULTURAL ACTIVITY PLAN

Figure II.A.2.—Example two procedure.

EXAMPLE THREE — ADDING CONTROLS WHEN PLANS DO NOT MEET WATER QUALITY OBJECTIVES

Example three procedure. — This example illustrates use of the controls procedure as a way to add new control opportunities to the silvicultural plan if the plan has been shown, through simulation, to fall short of the water quality objectives. (Fig. II.A.3 illustrates this application of the procedure.)

This procedure should be run several times, arriving at several control mixes that all meet the water quality objectives, to give the manager a choice.

1. Simulate (using the handbook simulation procedure) the water quality based upon the proposed silvicultural plan.
2. If the simulation procedure shows the silvicultural plan to meet the established water quality objectives, then no further reference needs to be made to the controls chapter. If the silvicultural plan is shown, through simulation, not to meet the established water quality objectives, then a new mix of controls should be selected using the controls procedure.
3. If objectives are not met, the simulation will show where the pollution is originating, how much pollution there is, and what kind of pollution is being produced. Using this information, first determine which variables within the simulation procedure are causing the pollution. Then, refer to table II.2 and relate the involved variables to the corresponding resource impacts (bare soil, compaction, etc.) (To relate the resource impacts to the involved processes — increased runoff, reduced infiltration, etc. — refer to the definitions of the resource impacts in the "Discussion" section of this chapter.)
4. When the water resource impacts have been identified, refer to section B or section C, tables II.3 to II.14, for a list of controls that could prevent the water resource impacts. At this point, a mix of such controls is selected and is added to, or used to replace, parts of the silvicultural plan. Determine which variables should be altered by referring to the tables in section C. The values of the variables should be altered to reflect the new control mixture before the next simulation. For example, if a simulation shows too much heat resulting from too much sunlight striking the water surface of a stream, the next step would be to check the cutting block design in the cutting and logging portions of the proposed silvicultural plan to find out which parts of the plan are directed toward the problem. If the plan calls for cutting blocks to be located too close to the stream, then a new control relating to cutting block design and location should be added to the plan to prevent water temperature increase.
5. Then use section D for description of the selected controls. Reference sources are listed in section D for those controls needing an expanded, technical definition.
6. Use section C to cross-reference the control opportunities with the variables and procedures used in the handbook simulation.
7. Simulate (using handbook procedures) the potential outcome of using the new mixture of preventive controls to meet the water quality objectives.
8. If the water quality objectives are met, no further simulations using different mixtures of controls are needed (unless economics dictate several simulations). If the water quality objectives are not met, new mixes of controls will have to be chosen and simulated again using the handbook procedures.
9. If after the addition of preventive controls the objectives are not met, the simulation will show where the pollution is originating, how much pollution there is, and what kind of pollution is being produced. Using this information, determine which variables within the simulation procedure are causing the pollution. Then refer to table II.2 and relate the involved variables to the corresponding resource impacts (bare soil, compaction, etc.). (To relate the resource impacts to the involved processes — increased runoff, reduced infiltration, etc. — refer to the definitions of the resource impacts in the "Discussion."
10. When the water resource impacts have been identified, refer to section B or section C, tables II.3 to II.14, for a list of controls that could mitigate the resource impacts. At this point, a mix of such controls is selected and

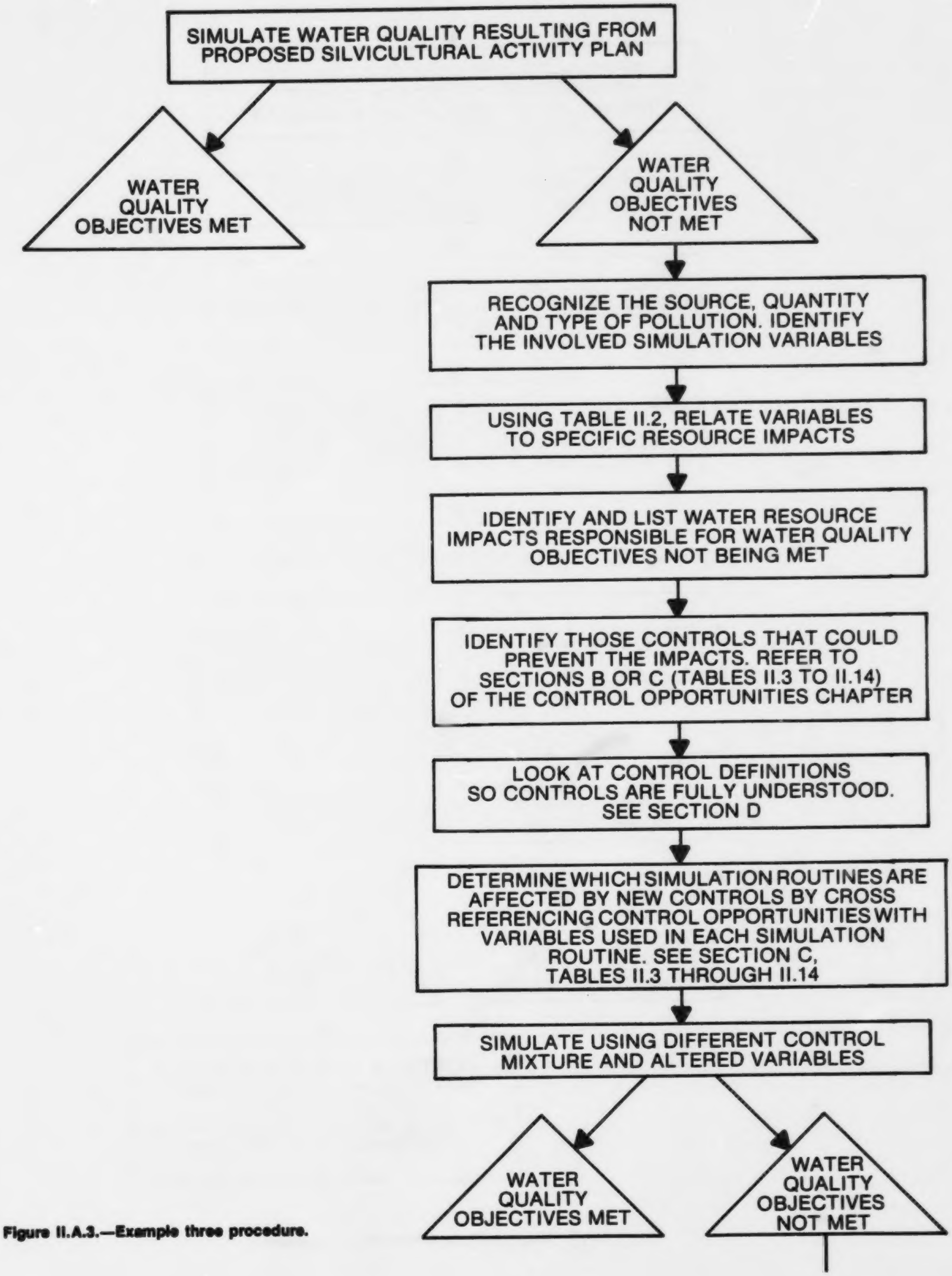
SIMULATE WATER QUALITY RESULTING FROM PROPOSED SILVICULTURAL ACTIVITY PLAN
WATER QUALITY OBJECTIVES MET
WATER QUALITY OBJECTIVES NOT MET
RECOGNIZE THE SOURCE, QUANTITY AND TYPE OF POLLUTION. IDENTIFY THE INVOLVED SIMULATION VARIABLES
USING TABLE II.2, RELATE VARIABLES TO SPECIFIC RESOURCE IMPACTS
IDENTIFY AND LIST WATER RESOURCE IMPACTS RESPONSIBLE FOR WATER QUALITY OBJECTIVES NOT BEING MET
IDENTIFY THOSE CONTROLS THAT COULD PREVENT THE IMPACTS. REFER TO SECTIONS B OR C (TABLES II.3 TO II.14) OF THE CONTROL OPPORTUNITIES CHAPTER
LOOK AT CONTROL DEFINITIONS SO CONTROLS ARE FULLY UNDERSTOOD. SEE SECTION D
DETERMINE WHICH SIMULATION ROUTINES ARE AFFECTED BY NEW CONTROLS BY CROSS REFERENCING CONTROL OPPORTUNITIES WITH VARIABLES USED IN EACH SIMULATION ROUTINE. SEE SECTION C, TABLES II.3 THROUGH II.14
SIMULATE USING DIFFERENT CONTROL MIXTURE AND ALTERED VARIABLES
WATER QUALITY OBJECTIVES MET
WATER QUALITY OBJECTIVES NOT MET

Figure II.A.3.—Example three procedure.

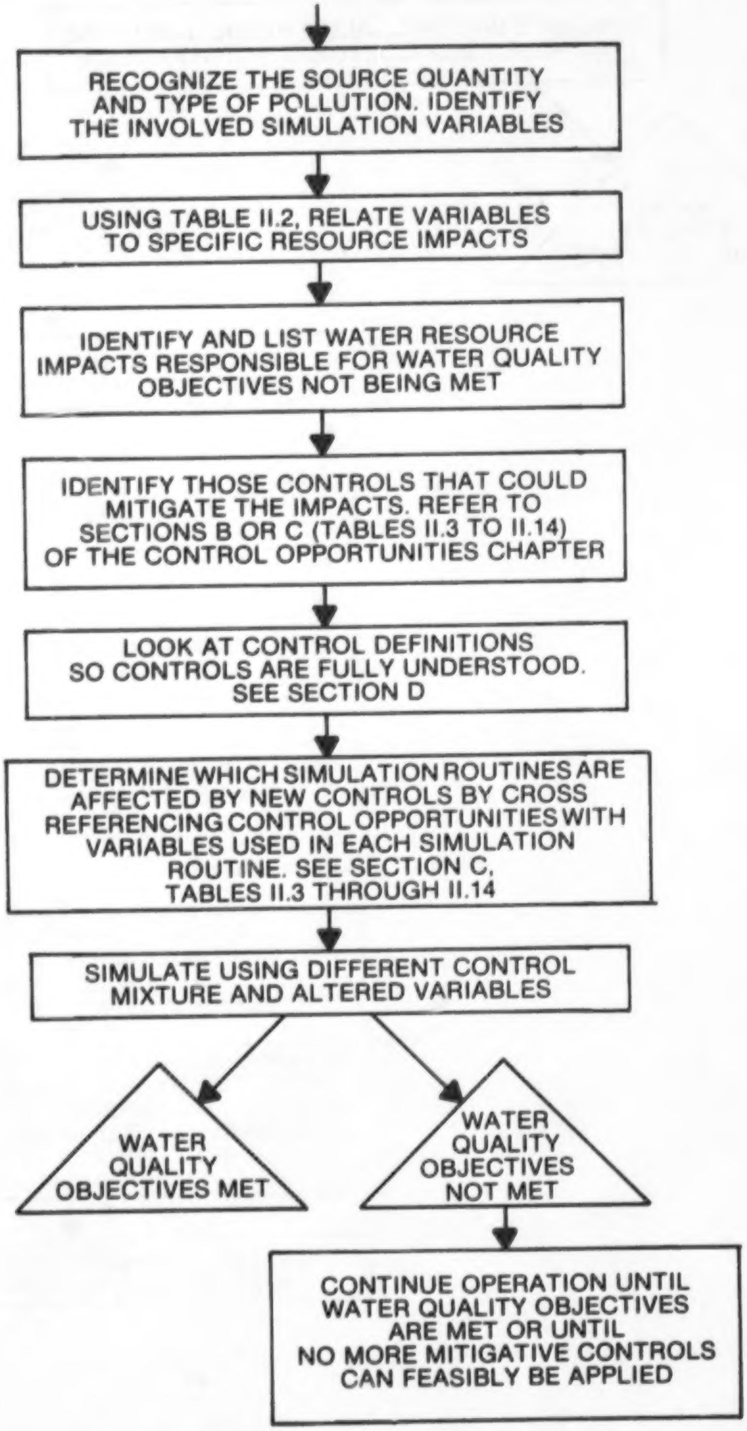
RECOGNIZE THE SOURCE QUANTITY AND TYPE OF POLLUTION. IDENTIFY THE INVOLVED SIMULATION VARIABLES
USING TABLE II.2, RELATE VARIABLES TO SPECIFIC RESOURCE IMPACTS
IDENTIFY AND LIST WATER RESOURCE IMPACTS RESPONSIBLE FOR WATER QUALITY OBJECTIVES NOT BEING MET
IDENTIFY THOSE CONTROLS THAT COULD MITIGATE THE IMPACTS. REFER TO SECTIONS B OR C (TABLES II.3 TO II.14) OF THE CONTROL OPPORTUNITIES CHAPTER
LOOK AT CONTROL DEFINITIONS SO CONTROLS ARE FULLY UNDERSTOOD. SEE SECTION D
DETERMINE WHICH SIMULATION ROUTINES ARE AFFECTED BY NEW CONTROLS BY CROSS REFERENCING CONTROL OPPORTUNITIES WITH VARIABLES USED IN EACH SIMULATION ROUTINE. SEE SECTION C, TABLES II.3 THROUGH II.14
SIMULATE USING DIFFERENT CONTROL MIXTURE AND ALTERED VARIABLES
WATER QUALITY OBJECTIVES MET
WATER QUALITY OBJECTIVES NOT MET
CONTINUE OPERATION UNTIL WATER QUALITY OBJECTIVES ARE MET OR UNTIL NO MORE MITIGATIVE CONTROLS CAN FEASIBLY BE APPLIED

Figure II.A.3.—Example three procedure — continued.

is added to the silvicultural plan. For example, if a simulation shows too much sediment resulting from road related surface erosion, the next step would be to check the transportation portion of the silvicultural plan to find out what controls directed toward the problem are part of the plan. If plans call for the road surface to be "dirt," then a new control (Protect Road Surface Area) can be added to the plan to mitigate the surface erosion.

11. Then use section D for a description of the selected controls. Reference sources are listed in section D for those controls needing an expanded, technical definition.
12. Use section C to cross-reference the control opportunities with the variables and procedures used in the handbook simulation.
13. Simulate (using handbook procedures) the potential outcome of using the new mixture of mitigative controls to meet the water quality objectives.
14. If the water quality objectives are met, no further simulations using different mixtures of controls are needed (unless economics dictate several simulations). If the water quality objectives are not met, new mixes of controls will have to be chosen and simulated again using the handbook procedures.

Chapter III

HYDROLOGY

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III.3 $\rho_{o\,adj} = 1 + (\rho_o - 1)\,(.50/X)$ III.17

III.4 $ET_A = ET_B \times C_{ET} \times RD \times$ Silvicultural State Area III.33

III.5 $Q_w = \sum_{p=1}^{i} (Q_p \times \text{Prescription Area/Watershed Area})$ III.35

III.6 $AR = \dfrac{Q_w}{Q_R}$ III.48

III.7 $Q_i = Q_{R_i} \times AR$ III.48

III.8 $RD = \dfrac{RD_w}{RD_A}$ III.49

III.9 $\Delta Q_i = b_o + b_1 Q_i + b_2 CD + b_3 AS + b_4 CD$ III.49

III.10 $Q_{average} = \left[.5(Q_1 + Q_N) + \sum_{i=2}^{N-1} Q_i \right] \times \dfrac{1.00}{N-1}$ III.50

III.11 $\Delta Q_i = b_o + b_1 Q_i + b_2 CD$
$+ b_3 AS + b_4 RD + b_5 \text{Sine Day}$ III.51

III.12 $\text{Sine Day} = \text{Sin} \left(\dfrac{360 \times \text{Day \#}}{365} \right) + 2$ III.51

III.13 $\rho_f = \dfrac{1 - \rho_{o\,adj} X}{1 - X}$ III.77

III.14 $ET_A = \sum_{i=1}^{n} \epsilon_i ET_i = \epsilon_1 ET_1$
$+ \epsilon_2 ET_2 + \ldots \epsilon_n ET_n$ III.94

III.15 $Q_p = \sum_{T=30}^{35} Q_T$ III.94

III.16 $(\text{cfs}) = \dfrac{\text{(inches) (watershed area in acres)}}{\text{(12 in/ft) (1.98) (number of days in interval)}}$ III.120

III.A.1 $Q = \left[5000/(1 + 250 \dfrac{1-a}{H}) \quad 0.87P_3 - 0.2\delta \right.$
$\left. + (0.13P_3 - 0.15\delta)\,a + (0.35\delta - 2P_3/3)b - P_3c/3 \right]$ III.148

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INTRODUCTION

The objective of the hydrology chapter is to present a methodology which will help to predict the potential impacts of silvicultural activities on the hydrologic cycle, or at least those components which most significantly affect non-point source pollution. The state-of-the-art in hydrology is such that a methodology cannot be presented in a handbook without falling short in terms of both process definition and predictive capabilities. The methodology presented was formulated using relationships developed from simulations using existing hydrologic models. The data bases used in the simulations were from representative and experimental watersheds and the relationships extrapolated for regional applications. Because of weaknesses of the state-of-the-art in modeling and in the limited number of data bases, many assumptions had to be made which weaken the methodology if misinterpreted. Correct application of the methodology is not a simple matter of "plugging in numbers and turning the crank." Because hydrology plays a role in virtually all aspects of non-point source pollution, the procedure should be carefully applied only by qualified individuals.

For this reason, an "Overview of the Hydrologic Cycle" is presented first. It describes the salient hydrologic processes in stream and storm flow generation that can be impacted by management and which have the most significant potential for influencing non-point source pollution. Another section, "The Impact of Silvicultural Activities on the Hydrologic Cycle," is also included to present a subjective means of evaluating the potential impacts that silvicultural activities can have on those key processes or components. It is believed that the qualitative sections will be useful to the technically oriented user of the handbook and enable the necessary assumptions and interpretations to be made regarding the methodology as it applies to the specific application. It has been found, for example, that presenting the various procedures for routing the components of streamflow — surface runoff, subsurface flow, and ground water — was not possible in a handbook given the state-of-the-art; yet the overview may help the user to make the right decision concerning the potential occurrence of and impact on each component.

DISCUSSION: OVERVIEW OF THE HYDROLOGIC CYCLE

The water balance. — The hydrologic cycle can be discussed in terms of the disposition of precipitation as expressed by the water balance:

$$P_g = R_o + E_t + \Delta S \qquad \text{(III.1)}$$

where:

P_g = Gross precipitation during a time interval t,

R_o = Streamflow or total water yield during a time interval t,

E_t = Evapotranspiration or precipitation which is vaporized and returned to the atmosphere by evaporation from the land and vegetal surfaces or transpired by the vegetation during a time interval t, and

ΔS = Change in storage or that portion of precipitation which is retained or lost from storage in the earth's mantle during the time interval t. The change in storage approaches zero as the time interval (t) increases.

Silvicultural activities have virtually no effect on the amount of precipitation entering the system but can influence the disposition of that rain or snowfall in both time and space on a small or local scale. It is by altering the components of the above water balance through alteration of the processes involved that man has the opportunity to influence the hydrologic regime.

Energy and precipitation. — The hydrologic cycle has two inputs: energy and precipitation. Energy controls both the form of precipitation as it enters the system (whether rain or snow) and disposition of the precipitation within the system. Figure III.1 presents the hydrologic cycle as a system of water storage compartments and depicts the relative transfer of liquid, gaseous, or solid water to the various components of the budget (P_g, R_o, E_t, and ΔS).

Precipitation falls in the liquid or solid phase or in combinations of both. Chow (1964) gives more detailed information on precipitation forms but three are assumed to be of significant interest to the forest hydrologist — rainfall, snowfall, and a combination of rain and snow.

Distinguishing between rain and snow. — Distinguishing between rain and snow (whether or not precipitation falls as water droplets or ice crystals) depends on complex thermodynamic processes. Obviously, when air temperatures are warm, it rains; when they are cold, snow falls. One method which appears to give a reasonable differentiation between rain and snow (or combinations thereof) can be illustrated by the following:

$$P_f = (1 - B/A) \qquad \text{(III.2)}$$

where:

P_f = The form of precipitation; rain, snow, or a mix (if $P_f \geq 1$ then precipitation form = snow, if $P_f \leq 0$ then precipitation form = rain, if $0 > P_f < 1$ then precipitation form = mix of rain and snow),

B = Difference between the maximum temperature (T_{max}), during some interval of time, and the temperature at which snow falls,

A = Difference between the maximum (T_{max}) and minimum (T_{min}) temperatures during the same interval of time.

and where:

T = Threshold temperature or temperature at which snow falls,

T_{max} = Maximum temperature during time interval, and

T_{min} = Minimum temperature during time interval.

If used with some judgment, equation III.2 should enable the user to make a reasonable differentiation between whether the storm event was rain or snow.

Evaluating snowmelt. — In the United States, snowmelt processes have been the subject of much study since the late 1930's.

Thermal indices provide reasonable estimates of melt when the objective is merely to predict snowmelt, the simplest being the air temperature method (U.S. Army 1960). However, thermal indices are not adequate for evaluating the snowmelt process because they do not adequately consider the complex energy exchanges that take place between the forest cover and snow environment. Chow (1964) treats the subject of snowmelt in some

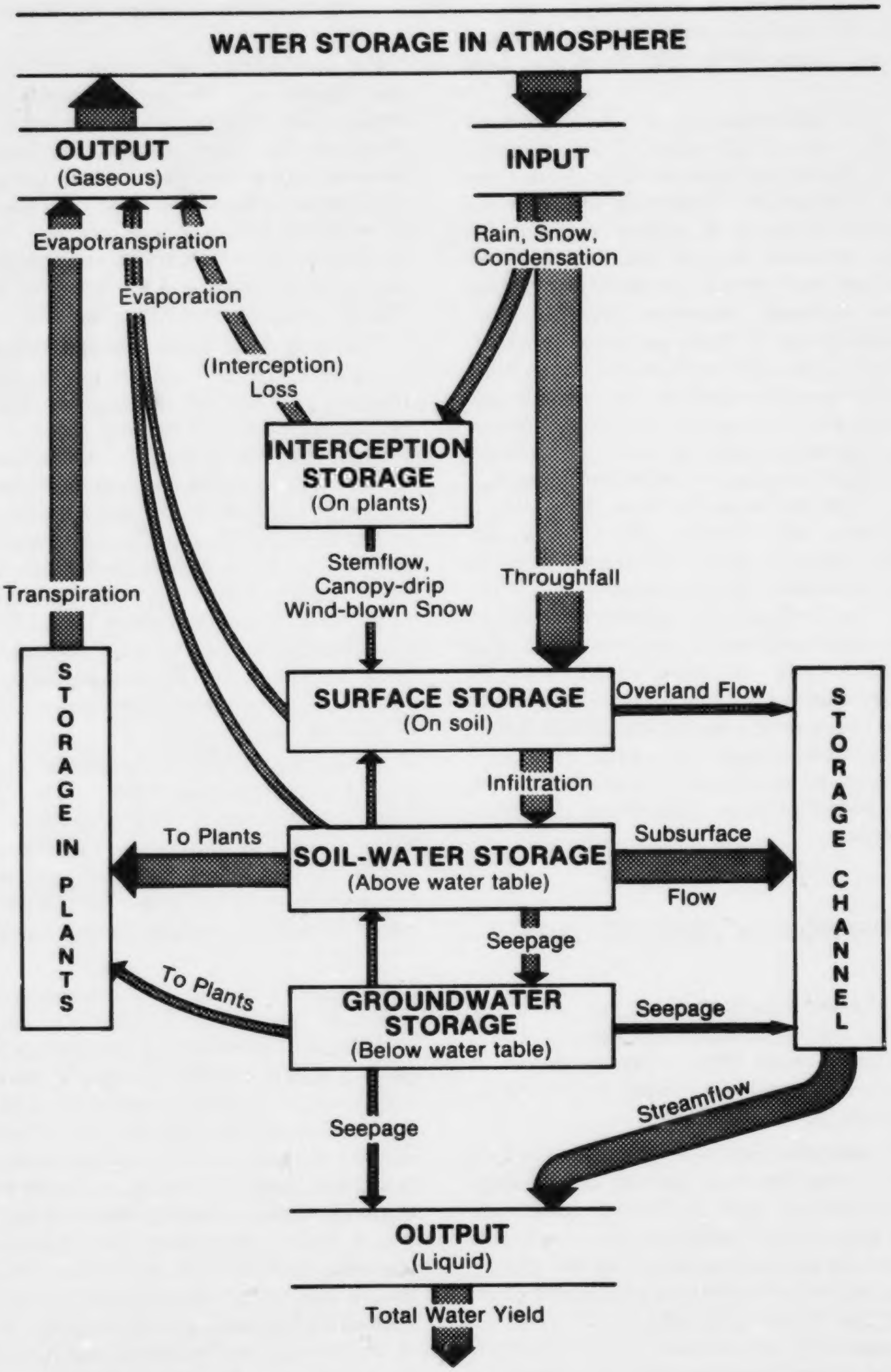


Figure III.1—The hydrologic cycle consists of a system of water storage compartments and the solid, liquid, or gaseous flows of water within and between the storage points (Anderson and others 1976).

detail. A comprehensive analysis of several watershed and snowmelt models will also be found in Sohn and others (1976) and Jones and Leaf (1975).

A practical quantification of the snowmelt process requires compromise. For example, research has shown that solar radiation is the principle cause of snowmelt. There may be exceptions in those areas where large sources and sinks of energy are involved in the sensible (convection/advection) and latent (evaporation/condensation) heat exchange processes. However, adequate determination of these exchange processes requires more data and sophisticated analytical tools than are normally available. Accordingly, the best approach is to: (1) consider the energy balance from incoming solar radiation and temperature, and (2) modify this balance to account for sensible and latent heat exchange in those areas where these processes significantly affect snowmelt. While solar radiation is the principal cause of runoff from snowmelt, in some parts of the United States (the Pacific Coast, for example) runoff can occur from combinations of both snowmelt and rainfall. Such rain on snow events can be catastrophic, causing severe erosion and mass movement. These are the largest streamflow events and occur in winter during wet mantle conditions. Thus, as discussed subsequently in this handbook, the runoff potential from both forest and open areas is similar.

DISPOSITION OF PRECIPITATION

As precipitation falls to earth, it can strike any one of several surfaces including foliage and stems of the vegetative cover, litter or organic debris on the soil surface, mineral soil, or open water such as streams, rivers, ponds, and lakes.

Channel precipitation. — Precipitation falling on the open water (channel system) immediately becomes streamflow and all further losses are beyond the scope of this handbook. Little that man does or can do in silvicultural activities has any effect on the channel precipitation component other than to increase it, either by reducing interception losses or increasing the amount of live channel. Normally channel precipitation represents a variable, but small, percentage of the total precipitation.

Effect Of The Canopy On Water Losses

For precipitation falling on the land mass, the first opportunity for loss occurs from that which strikes and is intercepted by the vegetative canopy. Water which wets or sticks to the canopy is either retained and evaporated back to the atmosphere, or detained and allowed to drop to the forest floor, or redeposited elsewhere (as in the case for windblown snow). A small percentage of the intercepted water runs down the branches and tree bole as stemflow and enters the soil.

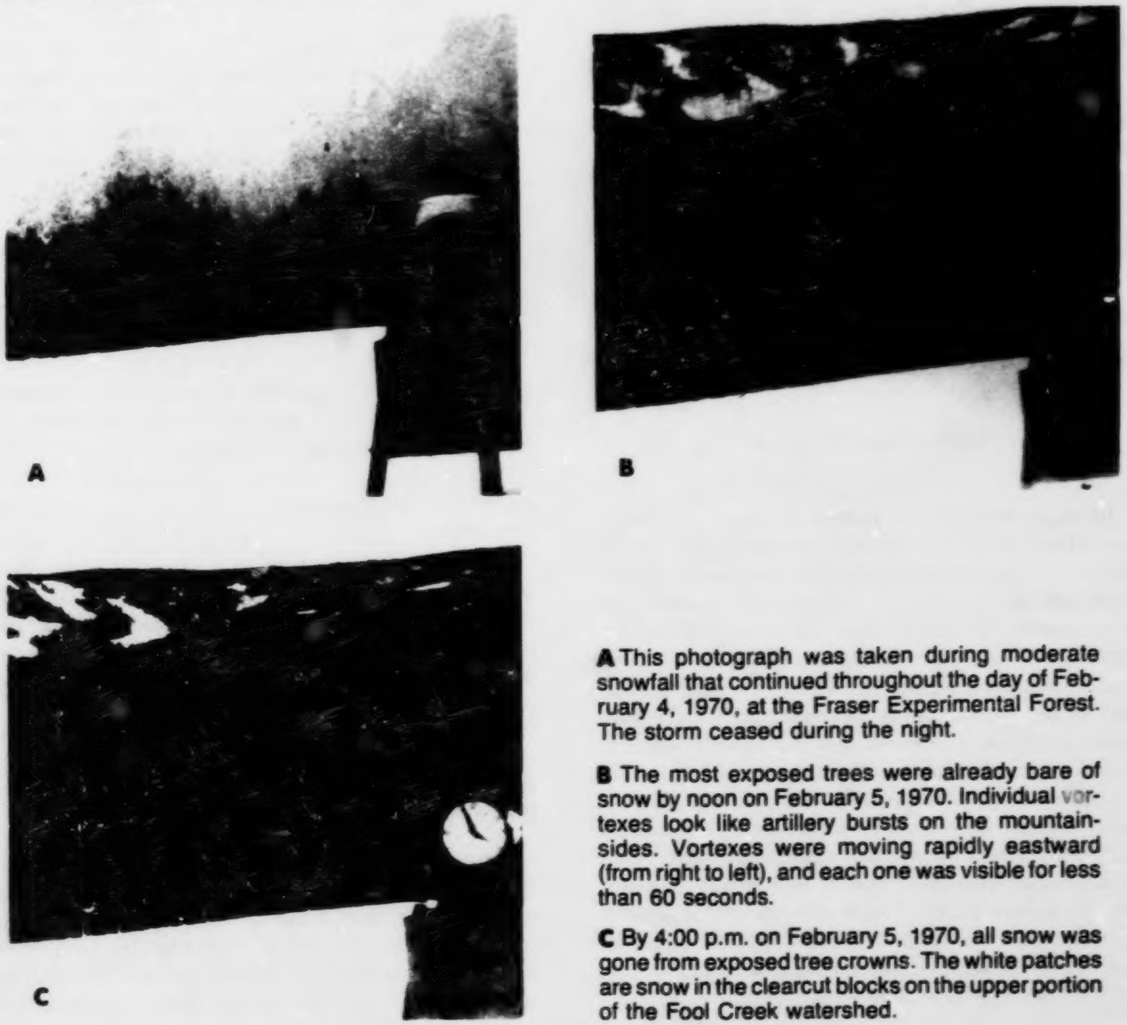
That portion of water evaporated back from the canopy is of the most concern, as it represents a loss from the system ("interception loss") as part of the evapotranspirational process. Several factors influence the magnitude of interception losses — crown density; species; season; latitude; and storm frequency, size, intensity and duration. Generally, it can be noted that conifers intercept more than hardwoods, and a greater percentage of precipitation in small volume storms is intercepted than in large volume storms (Helvey 1971a, Douglass and Swank 1975). In general, interception loss increases with increases in the foliage surface and the number of storms, and it decreases with increasing storm size and duration.

Several equations are available which can be used to estimate interception losses. These have been summarized by Helvey (1971a) for various tree species. The summary represents equations for individual events; and little difference was noted in seasonal interception losses for coniferous species, while deciduous species varied significantly by season.

Rainfall regimes. — Interception averages about 10 percent of the precipitation falling on deciduous forest stands in the summer and about 5 percent during leafless periods. On the other hand, fully stocked conifers intercept 15 to 20 percent in the summer and only slightly less in the winter. Assuming uniform rainfall, seasonal differences in interception losses in conifers are mostly a function of available energy. Conifers may annually intercept 4 to 6 inches more water than hardwoods under identical precipitation conditions (Douglass and Swank 1975). This observation is a generality for rainfall regimes and, as will be shown, is a function of the amount and seasonal distribution of both precipitation and energy. Under snow dominant regimes the process is similar, but the relative effect of interception may vary.

Snowfall regimes. — In some predominantly snowfall regimes, the snow may rest on tree canopies only during periods of cloudy weather, low temperatures and frequent snowfall. For example, in the Rocky Mountain region wind generated vortices and eddies quickly strip the snow from the trees. In a short time this airborne snow is redeposited at varying distances from where it was initially retained on the canopy (Hoover and Leaf 1967) and little loss occurs. In other geographic areas, redistribution may not be as dominant and thus may have a lesser effect on the seasonal snowpack. However large or small the impact of snow redistribution, the potential should be evaluated in all regimes (Anderson and others 1976). Significance of the redistribution phenomenon is illustrated in figure III.2, a time-lapse sequence of a typical snowfall event in central Colorado. In regions where snow interception loss is significant, one general equation for estimating the loss on coniferous trees has been proposed by Satterlund and Haupt (1967).

Whether in the form of rain or snow, interception losses occur from the gross precipitation (P_g) with the remainder (P_{net}) passing through to the forest floor. Precipitation (P_{net}) in the form of snow is delivered below the canopy and accumulates until it melts; precipitation (P_{net}) in the form of rainfall occurs as either stemflow, throughfall, or direct precipitation, which later has an opportunity for further loss by litter interception. Water from the melting snowpack is subject to litter interception much the same as rainfall.



A This photograph was taken during moderate snowfall that continued throughout the day of February 4, 1970, at the Fraser Experimental Forest. The storm ceased during the night.

B The most exposed trees were already bare of snow by noon on February 5, 1970. Individual vortexes look like artillery bursts on the mountainsides. Vortexes were moving rapidly eastward (from right to left), and each one was visible for less than 60 seconds.

C By 4:00 p.m. on February 5, 1970, all snow was gone from exposed tree crowns. The white patches are snow in the clearcut blocks on the upper portion of the Fool Creek watershed.

Figure III.2—Significance of wind-caused snow redistribution in the subalpine zone.

Effects Of Litter Cover On Disposition Of Precipitation

Litter interception loss is precipitation intercepted or detained by the litter on the forest floor and eventually evaporated back to the atmosphere without infiltrating the mineral soil. It ranges from 2 to 20 percent of the gross precipitation (Helvey 1971) and, like canopy interception, is strongly related to storm frequency and size. Litter interception loss normally averages only a few percent and represents a much smaller loss than canopy interception under fully forested conditions.

Benefits of the litter cover far exceed the cost in terms of water loss. Litter provides a protective cover which absorbs the energy of rainfall impact and prevents detachment of surface soil particles. It is far more significant in this respect than the vegetative canopy itself. The degree to which cover is effective in reducing rainfall impact energy at the soil surface is a function of where it is located with respect to mineral soil. Approximately 80 to 90 percent of the gross precipitation (P_g) reaches the mineral soil, and the closer the cover is to the mineral soil, the more effective it can be in reducing rainfall impact.

MOVEMENT OF WATER INTO THE SOIL WATER COMPLEX

Infiltration Of Water

In most undisturbed forests in humid and subhumid climates, rainfall and snowmelt usually infiltrate. (This is a general observation although there are exceptions.) In our general process considerations, we assume that all precipitation, except the interception losses or otherwise detained and evaporated water, infiltrates the soil mantle and at least temporarily becomes part of the soil-water complex. The limiting factor in infiltration of water into undisturbed soils is generally not the infiltration rate; this usually far exceeds normal precipitation intensities. Failure to infiltrate undisturbed soil is more often associated with a lack of soil-water storage capacity — there is no place for the water to go. There are regions and sites where a combination of storm size, frequency of event, and/or soil characteristics causes a failure in infiltration, but this is not the general case.

Factors Affecting Infiltration Rates — A Summary

Although infiltration characteristics of mineral soil are a function of several factors, the primary one is pore size distribution in the surface layer. The larger the pores, the greater the infiltration rate. Pore size distribution, in turn, is controlled by:

1. Texture. The parent material and its weathering. These determine the soil particle size or the proportion of sand, silt, and clay. Textural characteristics influence infiltration rates to some degree because sands have larger pores than do clay soils. Texture is independent of vegetation and, although it influences infiltration, it usually is not altered by man's activities.
2. Soil structure. The aggregates and macropores result from incorporated organic matter and tree-root and organism activity. Vegetation, directly and indirectly, is very significant in developing good structural characteristics and in maintaining high infiltration rates.
3. Soil moisture level. At the start of the event the antecedent soil water levels also influence infiltration since the drier the soil, the greater the initial rate, and the greater the capacity for storage.

Most forest soils are developed under conditions of adequate rainfall and profile development, at least at the surface (organic and mineral soil), which is adequate to insure an extremely high infiltration rate assuming storage capacity is available.

It should be noted that all factors which can greatly reduce the baseline infiltration are influenced either by the degree to which the surface organic layer and mineral are soil disturbed or incapacitated (such as by frost or mechanical means) or the degree to which storage capacity is reduced.

Evaluation Of Infiltration And Role Of The Soil Profile

Several factors need to be considered in evaluating the infiltration characteristics of a watershed or site. First, precipitation is not distributed uniformly over time so that the basin can recover or adjust to irratic pulses of intense precipitation. By the same token, antecedent moisture contents and infiltration rates are not spacially or temporally uniform, so that conditions which exist at one point may differ at another point and they can be compensating.

The infiltration process is a function of the physical and hydrologic state of the entire soil profile on which the precipitation (or melt water) is falling and, as suggested, is not necessarily restricted to a finitely thin surface layer. Assuming the surface layer is not saturated, the water infiltrates the surface and percolates vertically through the profile at a rate controlled by the conductivity of successively deeper soil horizons as the wetting front goes deeper. Assuming the rate of infiltration does not exceed the permeability of the deeper horizons, the water will tend to pass vertically. In many situations the deeper layers present a temporary restriction or impedance to the vertical movement of water when infiltration or percolation into the horizon exceeds the vertical rate of translation through it. Under these conditions, water is detained in the overlying layers and occupies available storage.

Depending upon input (rainfall or snowmelt) intensity and volume, and upon antecedent moisture conditions, saturation may occur in intermediate or even surface soil horizons. Once the rate at which water enters a horizon exceeds the rate at which water can leave the horizon vertically, the opportunity for lateral downslope movement increases. This applies whether the impedance or restriction to vertical movement is an underlying soil layer with restricting permeability or bedrock. Rainfall (rain, meltwater, or a combination) intensity has a significant effect on where lateral flow occurs in the mantle. Under low intensity input, bedrock may be the impeding layer; under more intense input, an overlying horizon may become the restrictive layer and become the impedance to vertical movement.

The rate at which water can move or be translated in the soil mantle is a function of the conductivity of the soil. The conductivity (K) is in turn a function of the soil moisture content (Θ) and, generally, the conductivity (K) has been shown to decrease exponentially with decreasing soil moisture content (Θ). Depending on antecedent moisture conditions, any horizon (especially those removed from the surface) may act as an impeding layer simply as a result of their low initial moisture content. This is more significantly associated with clay soils or soils with poor structural development.

The above discussion primarily describes the role the soil profile plays in infiltration; however, it also qualitatively establishes the conditions under which perched water tables are formed and rapid subsurface stormflow generated. Soil water movement in nonstorm periods is somewhat similar except that soil matric potential plays a more significant role and the time frame for movement is much longer. The discussion is valid everywhere and is primarily dependent on whether the profile described is several to many feet deep or only a few inches thick. In most forest situations, the surface organic layer and the surface mineral soil horizon are well developed both texturally and structurally and thus have adequate storage capacity. These layers then act as a buffer, absorbing the rainfall and either temporarily storing it or allowing it to pass on to other lateral or vertical positions. In this respect, mantle storage tends to dampen the effect of input intensity, thus allowing the system to dissipate the water internally. The two most significant factors in this process, then, are the size of the event and available storage capacity; when size exceeds capacity, failure to infiltrate occurs.

There are some sections of the country, and local sites everywhere, in which profile development and organic accumulations are inadequate for the infrequent but highly intense rainfall events, causing infiltration failure. By the same token, the effect of lateral downslope migration of water or lateral subsurface water movement can cause lower slope positions to fail more frequently than upper slope positions because of higher antecedent moisture conditions. Soil mantle constrictions or rock outcrops, soil freezing, and mechanical disturbance also alter this dynamic and variable process.

Dissipation Of Water In The Soil Water Complex

Water which infiltrates becomes, at least temporarily, part of the soil water storage. Depending on the hydraulic gradient or driving force in the soil, water may (1) be held in place, (2) follow the dominant gradient and percolate vertically or, (3) move laterally toward the stream channel. Further, water may be lost as part of the soil water complex through evaporation from the soil surface, deep seepage to ground water, quick flow to a stream, or absorption by vegetation roots and then transpirational loss to the atmosphere.

Transpirational Depletion Of Soil Water

The rate at which plants use water is a function of the amount of water and energy available to convert water to vapor (reflected by index parameters such as air temperature, solar radiation, wind, and vapor pressure deficits). Generally, during the growing season transpiration occurs at the maximum rate until water becomes limiting to the plant, at which time transpiration rate decreases; or, given the available energy, a fully stocked stand of vegetation will transpire at the maximum rate for the energy available as long as water to do so is not limiting. The actual function for any particular stand or site varies depending on soil characteristics, stand or cover density, species, and available energy and water. Silvicultural activities that reduce the canopy, change the plant-soil-water interaction.

Small watershed studies (Anderson and others 1976) have been effective in defining the water balance and its changes due to silvicultural activities. These studies have shown that a significant but varying amount is absorbed by, and lost through, the vegetation; the remainder (assuming no change in storage over the long run) appears as streamflow with a small but varying amount lost as either deep seepage or water that bypasses the stream gaging site.

Soil Moisture Regimes

Generally, soil water levels are highest during the dormant season or following seasonal snowmelt; levels are lowest during the mid to late growing season when accumulated transpirational drain is the greatest. This varies as a function of the precipitation regime, soil physical properties and depth, geology, position on slope, aspect, and the vegetation complex.

One example of a soil moisture distribution for a humid region with deciduous forest cover, uniform rainfall throughout the year, and moderate soil depth is shown in figure III.3. In this case, soil moisture recharge (see fig. III.3) begins sometime during the fall when precipitation exceeds evapotranspirational demand, thus resulting in a surplus of water. This surplus, in part, goes to storage and the balance results in higher streamflow levels. During the period of recharge, storage potential decreases, streamflow base levels increase, and the basin is potentially more responsive to individual storm events in terms of producing stormflow (not shown). During periods of maximum soil moisture deficiencies, basin response, in terms of percentage of precipitation returned as stormflow, may be low with the majority of precipitation stored in the soil mantle. On the same

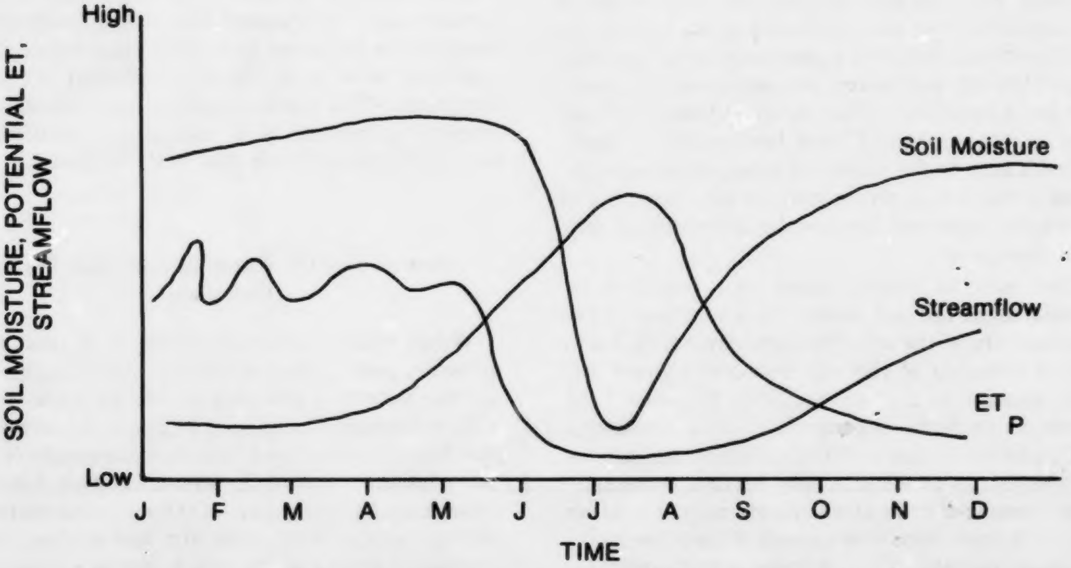


Figure III.3.—The relationship between streamflow, soil moisture, and evaporative demand in a deciduous forest in a humid environment.

basin, the response can be high during wet antecedent conditions (Hewlett, Cunningham, and Troendle 1977), when less storage capacity is available.

In humid regions such as the Pacific Northwest, non-point source pollution problems can be most critical when soil moisture storage capacity is minimal due to basin recharge. During this period the evapotranspiration processes have little influence on the quantity of water delivered to the stream and the runoff potential is equally high from both forested and open areas. In such cases, the stormflow analysis procedures discussed subsequently in this handbook are needed to evaluate silviculture's impact on water quality. The proposed methodology focuses on evaluating impacts on the hydrologic cycle from forest cover changes. This is not to say that other activities cannot have a significant effect in modifying hydrologic responses (road design, drainage, yarding, etc.) particularly during storm events. The user is encouraged to first consider the impacts from forest cover changes since modifications in antecedent conditions (soil moisture regime) must be known before making an adequate stormflow analysis.

The pattern expressed in figure III.3 varies with (1) soil depth and soil water storage capacity, (2) seasonal distribution and form of precipitation, (3) latitude (energy input), (4) vegetative cover, and (5) other factors. Consequently, this figure is representative only to illustrate the changing relationship of input, output, and storage.

Figure III.3 signifies the basic relation between precipitation and its disposition as streamflow, evapotranspiration, and soil water storage. Whenever storage capacity (or soil moisture deficit) is great or evapotranspirational potential high, streamflow can be expected to be low, although response to individual storms can be high. Streamflow and response to net precipitation will always be high when storage capacity is low or 0.

Streamflow Generating Processes

Interacting with the factors listed above is the relative role of various flow generating components of surface, subsurface, and ground water flow. The pathway that water takes to the stream channel controls its availability to be stored, to be used, and to carry pollutants.

As noted in the discussion on infiltration, we assume that almost all precipitation that is not intercepted infiltrates the soil mantle. This is a basic and significant assumption, since water which does not infiltrate has no opportunity for internal chemical exchange. By the same token, little opportunity is available to filter sediments and other pollutants from surface water if it has not infiltrated. Whenever man's activities alter the pathway water takes to the channel, the potential effect in changing water quality may be great. In effect, subsurface flow processes dominate the system and open water on the soil surface is observed only when the ability of the subsurface system to accept that water has been overridden. Furthermore, locally observed open water on the surface does not always leave the basin as overland flow. It must move all the way to the channel via the surface to be defined as true surface runoff or overland flow.

Describing subsurface water movement is exceedingly difficult because, like infiltration, it is such a complex process. We can assume, however, that gravity is the major driving force, and we can visualize the steady movement of soil water from the ridge to the stream (see fig. III.4). The maximum amount of water available at the ridge site in the ideal system is assumed to be limited to precipitation input, but at successive points downslope, the amount of water available exceeds local precipitation input by the amount draining from positions upslope.

As water migrates laterally downslope, it has the opportunity at any point to remain in place as storage, to migrate further, to be lost in the evapotranspirational process, or to percolate deeper as seepage to ground water.

Total available energy and water vary with position on slope, and, as a result, the various relationships presented in figure III.3 can be quite varied within the system. It has been shown that soil moisture can vary with season, aspect, crown density, position on slope, and soil physical properties, as well as with antecedent rainfall (Zahner 1967, Kochenderfer and Troendle 1971, Helvey and others 1972).

At any point in time, soil water storage potential per unit depth may be greater at the ridge than at channel positions. During a storm event or during active snowmelt periods, the lower slope positions (because of higher antecedent moisture and less available storage) which yield higher conductivities are more responsive and more influential in streamflow production; that is, streamflow and its solutes are most responsive to conditions that exist

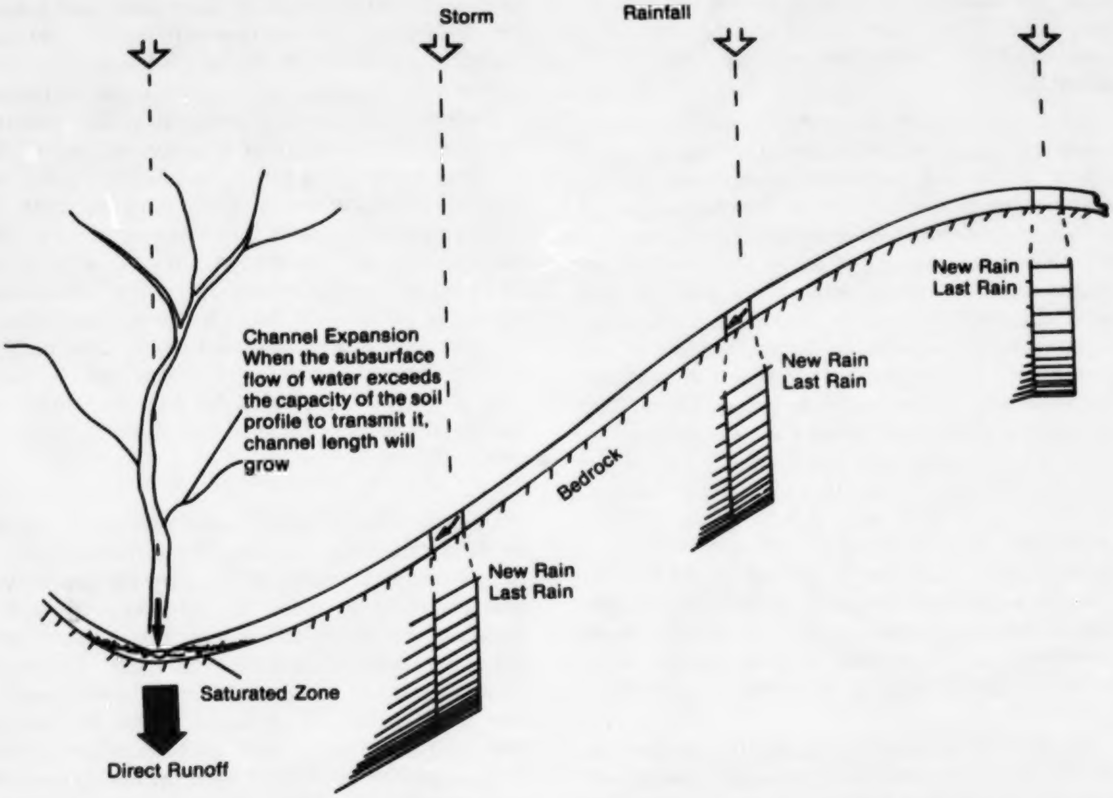

Storm
Rainfall
Channel Expansion When the subsurface flow of water exceeds the capacity of the soil profile to transmit it, channel length will grow
New Rain
Last Rain
New Rain
Last Rain
New Rain
Last Rain
Bedrock
Saturated Zone
Direct Runoff

Figure III.4.—Downslope movement of water on a forested upland watershed. This illustrates the variable source areas responsible for direct runoff and baseflow (Hewlett and Hibbert 1967).

at lower slope positions because these positions serve as a direct source and drain to the channel system.

The significance of this process is demonstrated for a watershed condition in figure III.5. At the start of the storm (or at any other time), the surface channel system needed to drain lower slope positions and headwater hollows exists at some level which is sufficient to drain the open water in the system. As the event (or time) proceeds, the lower slope positions, which quickly begin to yield water, and the channel system expands to drain this additional free water flowing from the saturated soil horizon. This continues through the rainfall event. Following the event, the source area recedes to something approaching the pre-event condition. This reflects the dynamic and variable nature of streamflow generating source areas and includes both storm and nonstorm periods.

Factors Affecting Individual Storm Response

Nature is never as uniform as idealized in the two preceding figures. First of all, soil mantles are seldom as uniformly distributed as depicted in figure III.4; there are depressions, outcrops, ridges, and swales. At the same time, soils vary both in physical properties and depth. As a result, storage capacity and moisture content are quite variable. Figures III.4 and III.5, however, contain the rudiments of the process: (1) water infiltrates; (2) water moves laterally downslope and concentrates; (3) when the capacity (saturation point) of the soil is exceeded, water exfiltrates; and (4) the process varies with slope length, soil depth, antecedent moisture conditions, and size of storm.

In the case of a rock outcrop or soil constriction at midslope, the downslope migration of subsurface water is impeded by the restricted soil depth.

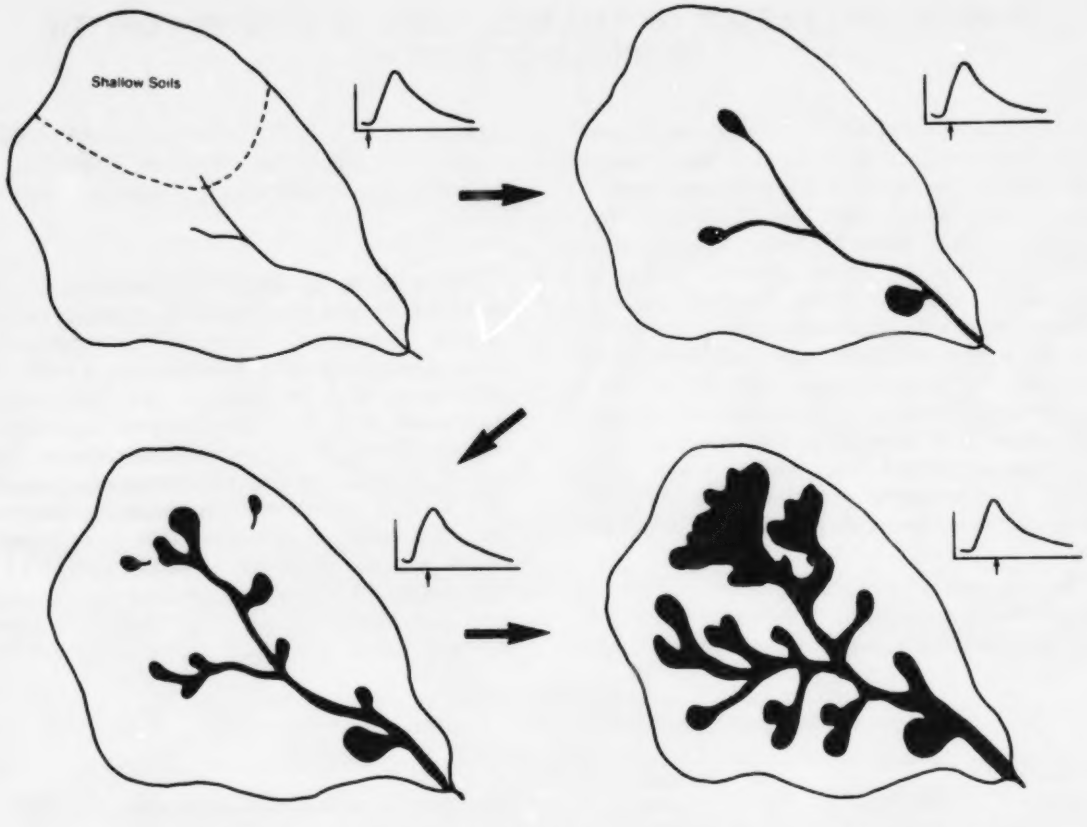


Figure III.5.—A time-lapse view of a basin showing expansion of the source area and the channel system during a storm (Hewlett and Troendle 1975).

Water storage capacity is decreased, and saturation may occur quickly. There is no place for subsurface water to go so it surfaces and travels overland in a draw or rill to the channel, becoming part of it. Similarly, wet weather seeps can be caused by contacts between soils of differing physical properties. Man-caused interruptions, such as roads, can act in the same manner.

The variability of soil moisture is such that stormflow sources in one storm may not be the same as those in the next. Systems not overloaded under small storms or dry conditions may become overloaded under larger storms or wet conditions. Seeps may occur as (1) sheet flow from either a continuous constriction or outcrop along a contour or (2) as a spring from a constriction in a swale where subsurface flow has concentrated.

Every basin has its own signature in this respect. Each must be interpreted individually. Water surfaced in this manner flows toward the channel. If conditions permit, it will reinfiltrate. In other cases, it may flow to the channel and become an extension of the channel system. Any precipitation falling directly on this channel extension is, in effect, channel precipitation.

Streamflow from both rainfall and snowmelt is generated primarily in this manner. The objective of this discourse is to dispel the idea that stormflow from undisturbed basins is generated as "precipitation excess" or water failing to infiltrate and flowing toward the channel as overland flow. Overland flow resulting from failure to infiltrate can dominate the hydrograph, but the likelihood is restricted to minor portions of the country, specific sites, or extreme rainfall events.

DISCUSSION: IMPACT OF SILVICULTURAL ACTIVITIES ON THE HYDROLOGIC CYCLE

Hibbert (1967) first summarized the results of 39 experiments conducted at various places around the world on the effect of altering forest cover on water yield. Since that date there have been numerous other studies (Anderson and others 1976). Cutting the forest reduces evapotranspirational demand, alters the soil moisture regime, and results in increased streamflow. While it is not a purpose of this handbook to review the literature, the following table summarizes some of the observed responses to forest cover removal which have been observed in United States. Table III.1 was reproduced from Anderson and others (1976). This reference provides a comprehensive review of the literature on impacts from forest cutting.

The objective of this section is to describe the process changes occurring in the hydrologic cycle that are responsible for the water yield changes summarized in Table III.1. The indicated response results from process modification. Depending on the region, the impact on the various processes differed.

The removal of vegetation increases the net precipitation and possibly its distribution by both reducing the amount of interception storage and, in some cases, causing the redistribution of snow. The infiltration characteristics of the experimental watersheds more than likely were not significantly altered. The most significant direct response to the various silvicultural activities summarized in table III.1 was the reduction in transpiration associated with eliminating vegetation. This is reflected in higher soil moisture levels, which contribute to both higher base flow levels and/or wetter antecedent conditions, and possibly resulting in greater direct runoff or quick flow during storm events.

Table III.1.—Increases in water yield following forest cutting, by forest type, geographic location, and type of cutting (Anderson and others 1976)

Forest area (acres)	Mean precipitation	Mean annual streamflow	Silvicultural activity	Percent of area of basal area (b) removed	Regrowth	Water yield increases by years after silvicultural activity:									
						1	2	3	4	5	1	2	3	4	5
	--- Inches ---					--------- Inches --------					------- Percent ---------				
				(1) Mixed Hardwoods, Western North Carolina											
40	72	31	Clearcut	100	Yes	14.4	10.9	10.9	9.8	7.9	66	46	29	26	31
33	75	30	Clearcut	100	No	16.8	13.0	11.7	11.4	11.2	65	—	—	—	—
23	71	24	Clearcut	100	No	5.0	3.7	2.3	4.4	3.1	—	—	—	—	—
85	81	50	Clearcut	50	Yes	7.8	6.1	5.1	4.4	3.9	—	—	—	—	—
70	79	48	Selection cut	22b	Yes	3.9	2.2	2.8	1.1	1.5	6	5	5	3	3
212	73	42	Selection cut	30b	Yes	Averaged 0.98 per year									
71	80	51	Selection cut	35b	Yes	Averaged 2.17 per year									
50	77	41	Selection cut	27b	Yes	Nonsignificant									
22	72	33	Riparian cut	12	Yes	Nonsignificant									
				(2) Northern Hardwoods, Central New Hampshire											
39	48	35	Cleared	100	No	13.5	10.8	9.4			40	29	19		
				(3) Mixed Hardwoods, Northern West Virginia											
59	57	30	Cleared	100	No	10.3					—				
85	60	23	Clearcut (except for culls)	100 (83b)	Yes	5.1	3.4	3.5	0.6	2.2	19	16	—	—	—
59	57	30	Clearcut	50	No	6.1	5.8				—	—			
38	59	26	Selection cut	36	Yes	2.5	1.4	0.3	1.2	−0.2	10	5	1	4	—
90	58	30	Selection cut	22	Yes	0.7	0.1	−0.7	−1.6	0.7	2	0	—	—	—
85	59	25	Selection cut	14	Yes	0.3	1.3	0.3	0.3	0.0	1	5	1	1	0

Table III.1.—continued

Forest area (acres)	Mean precip-itation	Mean annual steam-flow	Silvicultural activity	Percent of area or basal area (b) removed	Regrowth	Water yield increases by years after silvicultural activity:									
						1	2	3	4	5	1	2	3	4	5
	--- Inches ---					-------- Inches ---------					------ Percent ---------				
				(4) Oak Type, Central Pennsylvania											
106	37	13	Clearcut	20	No	2.7					17				
				(5) Douglas-fir, Western Oregon											
237	90	57	Clearcut	100	Yes	18.2	18.0				36	33			
250	90	57	Clearcut	30	Yes	5.9	6.4	5.9	11.7	8.9	16	14	19	38	24
				(6) Aspen and Conifers, Colorado											
200	21	6.1	Clearcut	100	Yes	1.4	1.9	1.0	0.8	0.5	19	27	16	12	12
				(7) Lodgepole Pine and Spruce-Fir, Colorado											
714	30	11	Clearcut	40	Yes	3.3	5.2	3.7	4.6	5.4	32	35	43	63	71
				(8) Mixed Conifers, Arizona											
1,163	27	3.2	Clearcut	16	Yes	1.2					16				
248	32	3.4	Selection cut	32	Yes	0.5	2.0	1.6	1.9	1.2	56	45	—	—	—
318	32	3.4	Selection cut	45	Yes	Nonsignificant									
				(9) Utah Juniper, Central Arizona											
323	19	0.9	Cabled, burned, seeded to grass	100	Yes	Nonsignificant									
				(10) Chaparral, Central Arizona											
95	26	2.2	Herbicide	90	Yes	3.4	3.0	2.6	9.8	14.2	111	292	589	451	235
46	26	2.2	Herbicide	40	Yes (grass)	3.0	0.9	1.8			299	517	223		
				(11) Oak-Woodland, Central California											
12	25	4.1	Chemical kill	100	Yes (grass)	4.0	7.9	4.0			25	65	300		
				(12) Chaparral with Woodland along Streams, Southern California											
875	26	2.5	Riparian cut	2-4	Yes	0.4					—				

Table III.1. — continued

(13) Ponderosa pine, Beaver Creek, Arizona

Watershed no. and year treated	Mean winter stream-flow	Silvicultural activity	Percent of area treated or basal area (b) removed	Difference between predicted and actual streamflow by years after silvicultural activity						Mean difference	
				1	2	3	4	5	6		
	Inches									Inches	Percent
12,1967	6.04	Clearcut	100	3.79	0.92	1.81	1.47	1.39	3.29	2.00	35
9,1968	6.70	Clearcut in uniform strips	32	1.98	.61	.34	.84	1.74		1.10	16
17,1969	7.63	Thinning	75	.85	1.45	1.51	2.93			1.68	222
14,1970	4.71	clearcut in irregular strips, thinning between strips	50	.71	.70	1.61				1.01	21
16,1972	5.45	As above	65	5.60						5.60	103

Blank = no data available; dash = no percent given in source reference.

THE BASIC HYDROLOGIC PROCESSES AFFECTED BY SILVICULTURAL ACTIVITIES

General Consideration — Vegetative Cover

In snowfall dominant regimes, vegetation will be briefly mentioned in terms of the parameter forest cover density. In rainfall dominant regimes, this parameter is leaf area index or vegetal surface.

Obviously, every stand has both a leaf area index and a cover density, but they may not be numerically correlated. Cover density is most significantly reflected in defining energy transmitted to the snowpack, while leaf area index relates to the potential for dissipating energy in the canopy through evaporation of intercepted water and by transpiration. The terms are conceptually synonymous, but differing definitions were required by the nature of the parameter use in the model used to develop the relationships for the handbook.

Forest Cover Density (C_d)

Forest cover density (C_d) is an index, which theoretically ranges from zero to less than one, and references the capability of the stand or cover to integrate and utilize the energy input to transpire water. It represents the efficiency of the three dimensional canopy system to respond to the energy input. It varies according to crown closure, vertical foliage distribution, species, season, and stocking. It is significant in defining the energy transmitted to the ground or the transmissivity coefficient. The cover density and transmissivity coefficient do not add up to one. Some estimates of cover density and transmissivity are listed in table III.2.

Table III.2.—Ranges of forest cover density and transmissivity

Forest type	Forest cover density	Transmissivity
Lodgepole pine	0.25-0.45	0.35-0.30
Spruce-fir	0.50-0.65	0.30-0.25
Aspen		
Foliated	0.35	0.35
Defoliated	0.20	0.50

The Leaf Area Index (LAI)

The leaf area index (LAI) is used in areas where precipitation is lost most significantly by the evapotranspirational process. It is the ratio of leaf surface area to ground surface area. Rather than indexing transmissivity, it indexes the area of the major intercepting and transpiring surface (the ratio of area of leaf surface to ground surface).

As the vegetation reoccupies an area that has been cut, forest cover density (C_d) or leaf area index (LAI) increases with time until reaching a maximum value with respect to utilization of water given the available water and energy. The rate at which forest cover reaches this plateau depends on environmental conditions, stocking levels, and species. For example, in subalpine coniferous forests in the Rocky Mountains, full hydrologic recovery can vary from 30 to more than 80 years. In contrast, in the humid climate of the eastern Appalachians, hydrologic recovery to pre-silvicultural activity levels can occur in just a few years.

Once adequate vegetation has been established on a cutover site, the time span for recovery to full hydrologic utilization or pre-silvicultural activity levels varies. These time spans begin after successful regeneration has been established. For Appalachian hardwoods the lag time between harvest and establishment may be less than 1 year, while it may be 15 to 30 years for spruce-fir in the subalpine. Hydrologic recovery may occur in as little as 5 years for Douglas-fir in the Pacific Northwest once the regeneration has been established.

Effects Of Silvicultural Activities On Precipitation

Precipitation is a key input to the hydrologic cycle. Though simply stated in the hydrologic equation (eq. III.1), it is affected by a host of dynamic processes which range from large scale meteorologic-topographic interactions to local precipitation that falls on a watershed surface.

Effect Of Silvicultural Activities On Precipitation As Rainfall

The distribution of precipitation which occurs as rainfall is affected to a lesser degree by silvicultural activities than distribution which occurs as snowfall. The most significant alteration due to silviculture takes place in the interception process. As these vegetative surfaces are reduced by timber cutting, so is interception loss; the result is that a greater percentage of gross precipitation is available to the soil water system.

Effect Of Silvicultural Activities On Precipitation As Snowfall

In some areas in which the major form of precipitation is snowfall, the meteorological-topographic relationship as it affects snow distribution may not be significant; but in other areas, it is. In the Rocky Mountain/Intermountain region, for example, snowfall is the dominant form of precipitation, and windblown snow dominates the regime. In this area, when the forest cover is removed through spatially distributed openings, snowfall distribution is changed. Put another way, the aerodynamic characteristics of the watershed are modified through silvicultural activities.

Objective methods for quantifying the universality of the effects of silvicultural activities on snow redistribution through snowblowing are not yet available, and quantification of these effects must be based on considerable judgment and experience in a particular area. However, a few generalizations can be made for those areas where it has been observed to occur, such as in the dry snows of the Rocky Mountains.

The aerodynamic change in roughness of the vegetative surface. — This modifies patterns of snow accumulation, so that more snow may accumulate in the cutover area and less in the uncut forest. Significant increases in snow accumulation near the center of small forest openings are largely offset by large decreases in snowpack below the undisturbed forest so that total snow storage on watersheds subjected to cutting is not changed. When openings are large, greater than 15H in diameter (H = height of surrounding trees), however, total watershed snow storage may be decreased through large sublimation losses and transport of snow out of the basin (fig. III.6). The technical basis and procedures for computing retention coefficients for openings beyond 15H were developed by Tabler (1977) and presented in appendix A. Figure III.6 can be used as a guide for openings beyond 15H, but for site specific applications beyond 15H, the equations in appendix A are recommended.

Retention of snow as a result of forest cutting. — Snowfall is the major form of precipitation in the Pacific Coast province (Sierra Nevada and Pacific North Coast) above elevations ranging from 6,000 feet elevation in the Southern Sierra Nevada to 4,000 feet elevation in the Northern Sierra Nevada. However, considerable quantities of precipitation fall as rain or mixed rain-snow at elevations up to 3,000 to 4,000 feet above these lower baselines. Snows are wet, and windblown snow may seldom result in appreciable redistribution of snow. The relation between snowpack depth and water content between snowpacks in the open and under various forest densities varies with (1) time of year (reflecting influence of differential melt); (2) percent of precipitation that was rain vs snow; (3) size of snowstorms (which affected placement of snow lodged on tree canopies); (4) species crown type; and (5) melt regime as affected by aspect.

Studies in Canada (Swanson and others 1977) and the United States show that any large retention of snow as a result of forest cutting can be an important factor in determining the amount of runoff. For example, in the lodgepole pine type in Colorado, this redistribution effect is not greatly diminished 30 years after timber harvest, in spite of regrowth of trees and associated increase in forest cover density. It is thought that changes in natural snow accumulation patterns produced by timber

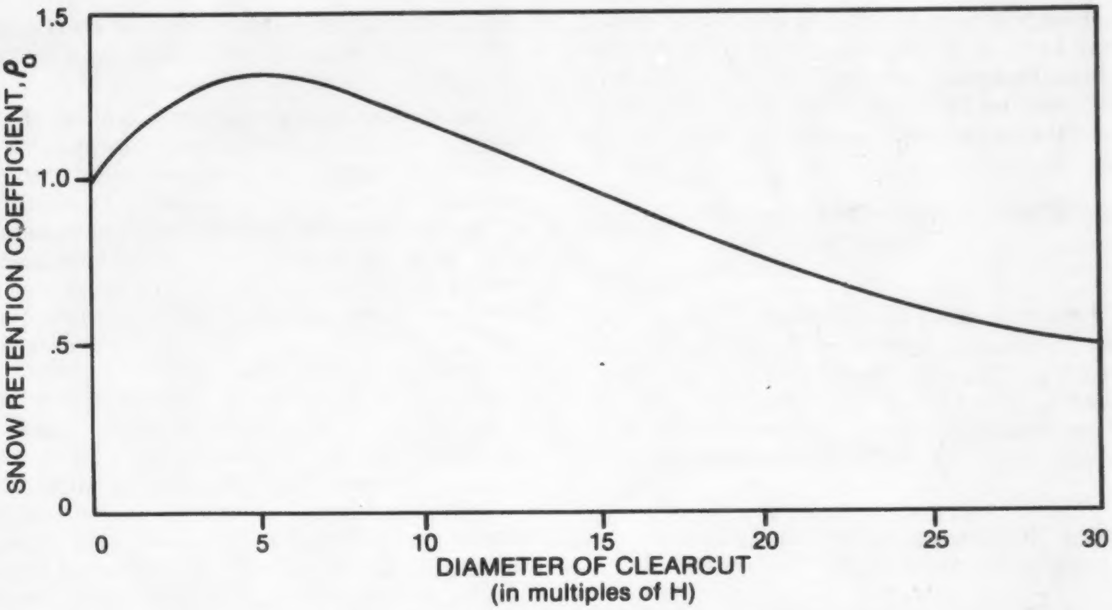


Figure III.6.—Snow retention as a function of size of clearcut. H is the height of surrounding trees.

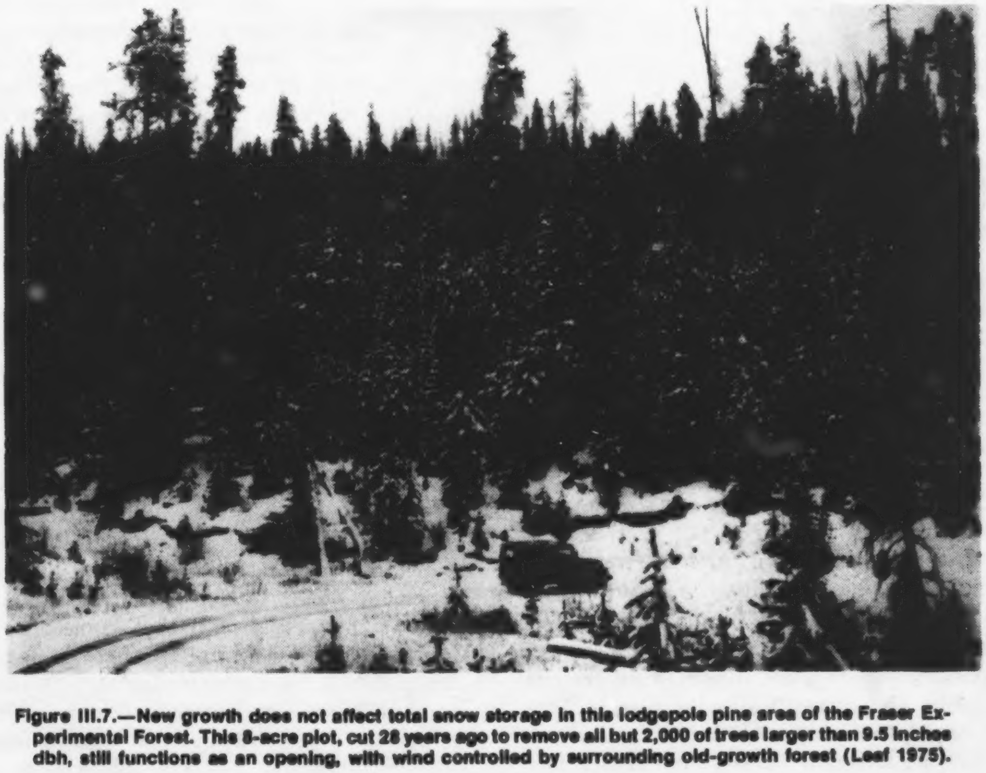


Figure III.7.—New growth does not affect total snow storage in this lodgepole pine area of the Fraser Experimental Forest. This 8-acre plot, cut 28 years ago to remove all but 2,000 of trees larger than 9.5 inches dbh, still functions as an opening, with wind controlled by surrounding old-growth forest (Leaf 1975).

harvest will persist until the new crop of trees approaches the height of the remaining undisturbed forest (fig. III.7).

The significance of the snow retention coefficient in the Rocky Mountains. — This lies in the opportunity that exists for both decreasing the net water loss from the pack and for altering the melt rate. As already noted, it can be expected that the transpiration losses in the openings will be decreased following cutting. The magnitude of increase in plant water use after cutting is dependent upon many items. One of the most important relates to size of the opening and the extent that roots from trees on the periphery reach into the opening. Also, if the area lies on a slope, some of the "saved" water resulting from transpiration reduction will migrate downslope into forested areas and be utilized by timber growing downslope from the cutover area. By placing a greater percentage of the total snow pack in these openings and less in the residual forest, one can expect to reduce the exposure of the net precipitation (in this case snow) to evapotranspirational processes. Because this snow is redistributed and because cover conditions have been altered, we are exposing a significantly greater proportion of the pack to sunlight, and can expect differing melt rates. In contrast, as the size of the opening increases (beyond 15H), the opportunity for increased ablation losses and wind scour can reduce the net precipitation below presilvicultural activity levels. This effect is significant in that it represents a net loss in water input to the system.

Optimum redistribution of snow. — In oldgrowth subalpine forests, optimum redistribution of snow occurs when (a) the stand is harvested in small patches of less than 5H in diameter; (b) the patch cuts are protected from wind; and (c) the patches are interspersed at least 5 to 8H apart. It should be emphasized that the redistribution theory is valid only when timber is harvested in small patches which occupy less than 50 percent of the watershed.

Since we are talking about a redistribution of a finite amount of snow, there is a contributing area for the increases occurring in the openings. The area of contribution is about equal to the opening; therefore, if the openings occupy more than 50 percent of the area, redistribution will be less efficient. In these situations ρ_o would have to be adjusted to reflect the limiting contributing area. If the area cut exceeds 50 percent, the following adjustment in ρ_o can be used:

$$\rho_{o\,adj} = 1 + (\rho_o - 1)\,(.50/X) \qquad \text{(III.3)}$$

where:

$\rho_{o\,adj}$ = adjusted snow retention coefficient

ρ_o = snow retention coefficient from figure III.6

$$X = \frac{\text{open area}}{\text{total impacted area}}$$

For purposes of this handbook, areas impacted by patch cutting can be defined by a perimeter around the cutting unit located approximately the width of the patch cuts away from them. It should be noted that wind protection implies an equal perimeter width below ridge tops and known wind exposed areas.

Effect Of Silvicultural Activities On Snowmelt Processes

The effect of silvicultural activities on complex snowmelt processes cannot be conveniently determined using a total energy balance model. A compromise procedure is to consider radiation as the primary energy source available for snowmelt and to concentrate on energy-vegetation interactions.

Snowmelt is assumed to be affected by: (1) Incoming shortwave radiation adjusted for the reflectivity on the snowpack; the net can vary from about 0.90 to 0.4, depending on such factors as age of the snowpack surface and other conditions; (2) longwave radiation balance between the snowpack and sky; and (3) the longwave radiation balance between the forest cover and snowpack.

These factors are, in turn, related to two parameters — transmissivity (percent of solar radiation which passes through the forest canopy to the forest floor) and the forest cover density, these will be discussed under the heading "Vegetation."

The addition of rainfall or snowfall to an existing snowpack is another factor determining the melt rate of snow, and thus the amount of water available for infiltration.

Effects of a rainfall event on snowpack energy. — Effects of a rainfall event on snowpack energy can be indexed by computing the caloric gain due to rainfall. If the snowpack is cold, the caloric input from the rain is used to satisfy all or part of the caloric deficit in the snowpack itself. If the input more than satisfies the deficit, then the remainder is expressed as energy in free water; the caloric input from that water is allowed to generate other melt.

The melt-producing capability of rain on snow is small, however. For example, 1 gm of rain at 8° C will release approximately 8 calories of energy/square cm to an isothermal pack. This will produce 0.1 g of melt or 1.1 cm of runoff. However, if the snowpack is cold, the rain will freeze and release an additional 80 calories of energy and may rapidly bring the pack to an isothermal condition.

Effects of condensation on snowpack energy. — In contrast, condensation on an isothermal snowpack is significantly more efficient in adding energy to the pack as it releases about 600 calories/gm of condensation/square cm. However, it is unlikely that more than a fraction of the total energy in the pack is added by condensation.

Effects of snowfall on snowpack energy. — For snowfall, the effects on the pack are similarly indexed by computing the caloric gain or loss due to snowfall. If the snow falls within the "warm" range of 32° to 35° F there is no caloric loss. However, snow falling at lower temperatures increases the caloric deficit.

As suggested by the brief discussion above, energy dissipation with respect to snowmelt is complex and alterations in energy balance due to silvicultural activities further complicate the process, both in respect to defining the process and in quantifying the process once defined. In summary, timber harvest may alter both the accumulation and the melt rate of the snowpack.

Effects Of Silvicultural Activities On Infiltration Rates

Unless soil disturbance occurs (which is always the case with roads, skid trails, or log decks), silvicultural activities do little to influence infiltration directly. Water will still infiltrate the undisturbed, unsaturated soil surface. It must be noted, however, that soil moisture levels may be higher following harvesting (as discussed previously) and available storage capacity may be decreased, depending on pattern and intensity of harvest, season, region, etc. Decreased storage will, in turn, limit the infiltration process in some places and, for some events, speed up the flow of subsurfce soil water in others, thus indirectly affecting the pathway of water to a channel.

It is beyond the scope of this section to attempt to quantify the impact of soil disturbance on either infiltration or water routing. Silvicultural activities result in mechanical disturbance of 5 to 15 percent of the harvest area (primarily in roads and skid trails). We have already described the potential for intercepting rainfall, snowmelt, and subsurface water with the road net. The problem is increased following harvesting since the soil will be wetter, the opportunity for intercepting subsurface water greater, and the potential for affecting the hydrograph greater. However, by properly locating roads, such as building them higher on the hillside, maintaining adequate drainage structures at proper intervals, and utilizing the other control practices recommended, the water falling on the disturbances and intercepted by the cuts can be redistributed over the basin and infiltrated prior to reaching the channel, thereby minimizing the impact on the hydrograph.

Influence Of Silvicultural Activities On Evapotranspiration

The evapotranspiration process is most significantly modified by silvicultural activities. Figure III.8 illustrates the relationship between stand reduction and evapotranspiration rates.

In figure III.8, E_a is the actual evapotranspiration rate based on stand condition and E_s is the potential rate computed by any one of a number of empirical equations. The figure demonstrates the relationship between fully forested (complete hydrologic utilization), open (minimum hydrologic utilization), and intermediate conditions indicative of the range of relative water use immediately after, and several years after, harvesting. One may reasonably assume that water use under

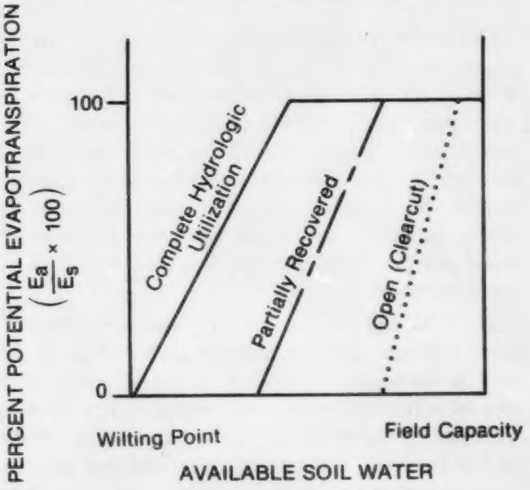


Figure III.8.—Relationships showing evapotranspiration as a function of available soil water for: Old-growth forest and open conditions and complete hydrologic utilization.

complete hydrologic utilization during the growing season proceeds at rates limited *only* by available energy until soil water itself is depleted to some threshold value. The threshold assumed in figure III.8 is 50 percent of the maximum available for transpiration (i.e., 50 percent of the field capacity index); thereafter, transpiration is assumed to decrease in proportion to the amount of soil water below one-half of the field capacity index.

Under the open condition, actual evaporative loss occurs at the potential rate when the soil is at or above field capacity, but it drops to zero very quickly as the soil dries slightly below field capacity.

As forest vegetation reoccupies cutover areas (i.e., the partially recovered curve) and consumptive use is increased, the relationship expressed in figure III.8 changes until, as the forest cover is reestablished, it ultimately approaches that of the fully occupied forest. It is this phenomenon which is primarily responsible for diminishing water yield increase over time following timber harvest. The rate at which this transition occurs depends upon forest species, climate, and stand conditions.

The rate at which complete hydrologic utilization is reestablished depends also on the type of vegetation that reoccupies the site and on its origin and subsequent management. Some tree species (for example, spruce-fir forests) are very difficult to regenerate and, therefore, require the longest period of time for regrowth. Other species, such as northern hardwoods, do not require as much time to reestablish themselves. Finally, many cutover areas can be subjected to vigorous regrowth — be it from sprouts, seeds, or herbaceous vegetation — and as a result, complete hydrologic utilization of the site takes place in a relatively short period of time.

The implication which can be drawn from the relationship expressed in figure III.8 is that the result of a reduced transpirational loss will maintain higher soil moisture levels. We have already described the potential effect of the higher antecedent conditions on infiltration, storm response, and increased flow levels.

In humid regions, the increased growing season flow levels can increase the length of the first order perennial channels. This can be effective in increasing the amount of channel precipitation, although this will have minimal effect on the hydrograph. More important might be the continual channel scour associated with the lengthened channel.

SUMMARY

The potential impact any silvicultural activity will have on the hydrologic response of a basin, either short- or long-term, can be evaluated in terms of the changes which will occur in the balance components of precipitation modification, evaporative changes, and storage changes.

In considering the impact of the removal of forest cover on evapotranspiration, soil moisture and streamflow levels, we have described the expected changes. There are exceptions, especially local problems, which need to be interpreted and evaluated by the user.

For example, in the black spruce bogs and fens of the Lake States region, strip and clearcutting experiments have shown little effect of treatment on annual water yield from high water table organic soils (Verry 1976). Higher water tables have been observed on these sites during rain events following clearcutting, while these same sites have lower water tables during extended dry periods; but on an annual basis, there is no net change in either the evapotranspiration loss or water yield. Apparently, high water table areas evapotranspire at the maximum rate regardless of the vegetation present. This assumes, of course, that free water is available at the surface, either directly through organic "wicking" or by the presence of adequate lush lower vegetation. The same principles would apply to other high water table sites in both organic and inorganic soils throughout this and other regions. Whenever the water table is at or near the surface, evapotranspiration will occur at or near maximum rates, regardless of the vegetation present, and any modification in the vegetation due to silvicultural activities will have little effect on evapotranspiration or streamflow.

In using the subsequent methodology to evaluate the impact of silvicultural activities on the hydrology of the planning unit, the user is cautioned to weigh the effect, if any, of the presence of high water table sites, regardless of the hydrologic region. Needless to say, a significant portion of the Lake States, New England, and Coastal Plain regions would have high water areas on which silvicultural activities would have little effect on the total water balance. This represents one of many localized site specific situations where the user will have to adjust the methodology-derived answer to fit the application. The basis for doing so is outlined in the discussion on the hydrologic cycle and management impacts on it.

PROCEDURE: EXPLANATION OF THE METHODOLOGY FOR PREDICTING IMPACTS OF SILVICULTURAL ACTIVITIES ON THE HYDROLOGIC CYCLE

PROCEDURAL FLOW CHART

The basic procedural steps for estimation of water yield changes due to silvicultural activity are presented in chapter I. More detailed flow charts are presented in subsequent procedural sections. They appear as figures III.9, III.21, III.23, and III.57.

PROCEDURAL DESCRIPTION

This section contains the procedures and methodology developed to predict the impact of silvicultural activities on the hydrologic cycle, and is presented in a regional format. The regional coefficients and modifiers were developed from simulations using available hydrologic models. The specific models and assumptions for their use are presented and documented in appendix B.

The continental United Sates was stratified into five hydrologic regions, as depicted in figure III.9a, based on major climatic and hydrologic influences. Observed data from representative and experimental watersheds from each region were used to calibrate the models. The data base, in terms of the number of calibration years and the number of watersheds, varied for each region and each model. However, given the constraints, all available data were utilized. Time was the most critical factor, but data were also limiting in terms of both availability and in terms of the format in which it was available — if it existed. In calibrating the models, there was no true statisitcal evaluation of the simulation; "goodness of fit" was subjectively interpreted by how well the simulations matched either the observed hydrograph, soil moisture distributions as they were understood, or local evapotranspiration estimates.

The objective was to extrapolate the experimental observations for regional use. Admittedly, the effort did not produce a comprehensive work reflecting all the regional variability; therefore, site specific information should be supplied whenever possible. However, the total effort is geared to the long-term, annual and seasonal water balance, by region. In this respect the methodology is adequate for characterizing response, given the current state-of-the-art.

In essence, the methodology extrapolates the results of research and long-term observations on specific sites to other offsite locations. The methodology is intended to complement sound scientific judgment, not replace it; and to insure reasonable evaluations where, because of the lack of experience, the judgment is less than optimum.

Use Of Site Specific Data

The format used in developing the analytical procedure segments the methodology to allow incorporation of local or site specific data bases where possible or to allow use of differing assumptions or techniques, if necessary, so that the analyses would be more site specific. The coefficients and modifiers presented are regional and should be used only if a site specific data base is not available. The analytical framework presented is sound, however, and will yield reasonable results which are applicable in the respective regions.

For example, the variability in regional snowpack development and characteristics has been recognized, but not all variability has been addressed. The main concern was to look at the response to the input of water within the framework of a hydrologic balance. The energy balance equations used in developing the snowpack relationships are radiation- and temperature-driven, and the results should be compatible in each region. The basic principles in the snowmelt model used in the simulation analysis were developed in the Far West and recently adapted for use in the Rocky Mountain/Intermountain region. Thus, it is believed that the simulation of snowmelt and rain-on-snow occurrences in the Central Sierra and Pacific Northwest, for example, are reliable. A review of current modeling procedures applicable to these regions did not lead to other conclusions.

The site specific role of certain relationships also needs to be evaluated. Based on research, primarily in the Rocky Mountains, snow retention coefficients are to be used to "redistribute" snow following cutting in those areas where blowing snow is significant. However, blowing snow is not necessarily significant everywhere that snow occurs. This requires an interpretation. By the same token, the retention coefficients themselves may not be exact for every site on which blowing snow does occur, requiring another decision. The relationship is, however, the only one that has been quantified. Its use is recommended if a site specific improvement is not available.

The same cautions apply to the estimates of regional evapotranspiration, the estimates of rooting depth impacts, and so on. Any site specific information should improve the evaluation. In many applications, however, there may not be site specific data available.

Use Of The Annual Or Seasonal Hydrologic Budget

The methodology is oriented toward the annual or seasonal hydrologic budget. It is recognized that the most significant opportunity for impacts on non-point source pollution may be associated with individual short-term events. In the South or East these may be large rainfall events or thunderstorms. Combined events such as rain-on-snow may be extreme in areas such as the East, the Northeast, or the Pacific Coast. The magnitude of the response to these events, however, is a function of the time of the year in which they occur (reflecting antecedent conditions), the size of the event (be it rain, rain-on-snow, etc.), and its duration.

As part of evaluating the potential impact of the silvicultural activity on these events, the long-term balance should first be evaluated and then the short-term event superimposed on the evaluation. Obviously, if the soil moisture regime is the same in both the undisturbed forest and the harvested area (as is known to occur during winter in many areas), a significant change in the magnitude of the event may not be expected (assuming the routing or pathway water takes to the channel has not been significantly altered). For example, rain-on-snow events most often occur when basins are recharged, regardless of the vegetal state; although the hydrologic response may be extremely significant, the effect of the silvicultural activity itself may be insignificant. Summer events are often significantly increased because of higher antecedent moisture following harvest. But because neither forest nor harvested area is likely to be fully recharged during this period, the respose will still not be as great as if the event occurred at a time when the basin was recharged. Therefore it is necessary to deal with such events individually on a "design-storm basis." Basic understanding of the processes that govern stormflow is weak, but standard methodologies for prediction are referenced, nevertheless. The most significant basis for characterizing changes in design storm response due to silvicultural activities results from changes which occur in the long-term hydrologic balance and is reflected in the antecedent soil-moisture conditions.

No Quantification On The Hydrologic Impact Of Mechanical Disturbances

Quantification of the hydrologic impacts of mechanical disturbance such as roads, log decks, and their location cannot be made, although they have been have qualitatively defined in the earlier sections in this chapter. Using the criteria described, the impact of the disturbances on the hydrology can be minimized using best management practices; and subsequent chapters deal more directly with their impact on pollution and appropriate controls.

The Importance Of Onsite Response

The overall methodology deals with onsite responses. The ultimate response in the channel or at some point downstream is a routed response which integrates the complexity of the basin, the location of the silvicultural activity, the area actually logged, and the routing characteristics of the watershed. Do not interpret the onsite responses determined by the proposed methodology as being a streamflow response, unless local data justify this assumption. On small (first order) headwater streams, the assumption may be justified. (The example presented in this handbook was developed with the assumption that onsite responses closely approximate streamflow responses.)

Use Of Models To Simulate Hydrologic Response

Two models were selected (see appendix B) to simulate the hydrologic response of differing levels of harvest on the hydrologic balance. The models, PROSPER (Goldstein and others 1974) and the Subalpine Water Balance Model (WATBAL) (Leaf and Brink 1973a, 1973b), were used to develop the hydrologic methodology and procedures presented in this section. Calibration and validation of WATBAL and PROSPER are presented in appendices C and D, respectively. Regional evapotranspiration, soil moisture regime, and water available for streamflow represent simulated averages using the data base available for the models. The modifier coefficients presented to adjust the various components of the hydrologic balance reflecting aspect, rooting depth, and elevation as a function of silvicultural activity were developed from simulations also.

There are several points to be made about the models.

An evaluation of the methodology (and the actual modifiers) was made based on how well the procedural estimates compared with observed changes from cutting experiments on various experimental watersheds. Because of its nature, the emphasis of the procedure may appear to generate absolute values for the annual balance; however, the objective is to estimate the change in the balance that will result from a particular activity. As such, the methodology is intended primarily as a planning tool useful in evaluating the relative hydrologic impact of various management alternatives. Although the regional variability of the hydrologic balance is great in terms of absolute numbers, the strength of the procedure is in terms of estimating the expected change (the variability of which is not as great); thus, the inherent errors are not nearly as large.

The prodecural format is to evaluate modifications in the evapotranspirational demand before and after vegetal modification. Potential changes are then translated to reflect changes in the soil-moisture budget. The significance of any soil moisture or antecedent changes is then reflected in terms of either potential changes in short-term storm response or in long-term streamflow levels.

To those reading both sections on the basic hydrologic regimes (rainfall and snowfall), discrepancies in regional technique will seem apparent. The inconsistencies are real only to the extent that the technique has been fitted to a form best suited to the confidence in the modeled output generated for each region. The point is that inconsistencies in methodology are not real. This chapter provides techniques for predicting the general impact of various silvicultural activities on streamflow, evapotranspiration, and soil moisture as a function of aspect, soil depth, season, position in the watershed, cover type, and climactic regime. The format for presentation varies, but is consistent with accepted practice in each hydrologic region and the overall objectives of the handbook.

Although all of the major hydrologic processes were simulated, only those responses critical to evaluating the impacts of silvicultural activities on non-point source pollution are presented. These include evapotranspiration, soil moisture, and water potentially available for streamflow.

Evapotranspiration

The baseline hydrology of the representative watersheds was first simulated; then the forest cover was manipulated through a range from full cover through various partial cuts, to complete removal. The vegetation reductions were made systematically, holding all other factors constant (soil depth, aspect, etc.). In some cases the other parameters (depth, aspect, etc.) were then altered systematically over all cover densities. Then the modifier coefficients, or the percent change, were developed and extracted. These characterize the change in evapotranspiration — annual and seasonal — for various cover density changes as a function of position, aspect, soils, latitude, and precipitation regime. This gives a technique for estimating evapotranspiration changes.

Outflow

The most useful output from the analysis in terms of non-point source pollution are the estimates of baseline and post-silvicultural activity levels of streamflow. Techniques are presented to predict baseline flow relationships. These must then be adjusted to get post-silvicultural activity levels. (1) For those regions where hydrographs are controlled by snowpack melt, the annual hydrograph is more typically uniform and the techniques deal with shifts in a "normalized" annual hydrograph of 6-day flow levels. (2) For the rainfall regions, a "normalized" annual hydrograph will not be presented. Although flow in these regions does follow a predictable cycle, the responses to individual events and other variances are too great to "normalize." Instead, an expected flow duration curve for average 7-day flow levels is presented. The expected flow levels can then be adjusted for the proposed activity.

Using this approach, users of the handbook can supply their own baseline flow duration curve or hydrograph, if available, and adjust it using the techniques presented; or they can use the normalized curve presented. Based on the simulations, baseline flow levels can be adjusted to represent treatment effect to an adequate degree. However, the state-of-the-art and nature do not permit simulation of the actual time dependent baseline conditions for presentation in a handbook format.

Soil Moisture

Soil moisture distributions, annual and seasonal, were extracted from each of the simulations to quantify the adjustment in soil water deficits associated with cover changes, again as a function of position, aspect, soil depth, and precipitation. These moisture level adjustments can then be used to adjust the antecedent moisture condition for the pre- and post-silvicultural activity storm flow predictions which follow.

Definitions Used

In the hope of minimizing ambiguity and increasing accuracy, several terms require precise definition. The following definitions are intended for use in "Hydrology."

Condition. — Refers to the hydrologic state of the watershed, i.e., baseline, existing, or proposed.

Baseline condition. — The hydrologic state of the watershed in which complete hydrologic utilization is achieved. It may be thought of as, but is not necessarily the same as, a fully forested watershed with vegetation (primarily trees) capable of maximum evapotranspiration (ET) for the energy and water available.

Existing condition. — The current hydrologic state of the watershed. It may differ from the baseline condition in that hydrologic adjustments have been made for vegetation differences from the baseline condition. The existing condition is synonymous with the "pre-silvicultural activity condition."

Proposed condition. — The hydrologic state of the watershed following a proposed silvicultural activity. It is synonymous with the "post-silvicultural activity condition."

Silvicultural prescription. — The management alternatives applied to a watershed or watershed subunit. The delineation of a watershed into a single unit or series of subunits to which the prescription is to be applied is based on uniformity of soil depth, vegetation, precipitation, aspect, and other unique site factors. A uniform practive over the entire unit or several practices resulting in more than one silvicultural state per silvicultural prescription; i.e., the prescription may consist of patch cutting, thinning, and leaving part of the area uncut.

Silvicultural state. — The status of the vegetation complex on units of land to which a silvicultural prescription has been applied. A silvicultural system or treatment actually applied to a unit or a description of the vegetative cover on all or a part of the unit. The state may be described as clearcut, thinned, forested, open, etc.

Treatment. — Action taken on vegetation by nature or man, including no apparent action. Silvicultural prescriptions may consist of several treatments.

Impacted area. — This refers to uncut and cut zones of the watershed which are affected by silvicultural prescription.

Unimpacted area. — Those zones of the watershed which are unaffected by a silvicultural prescription.

PROCEDURAL DESCRIPTION: DETERMINING EVAPOTRANSPIRATION AND WATER AVAILABLE FOR STREAMFLOW (ET ESTIMATION) (RAIN DOMINATED REGIONS)

APPALACHIAN MOUNTAINS AND HIGHLANDS (REGION 2)
GULF AND ATLANTIC COASTAL PLAIN AND PIEDMONT (REGION 3)
PACIFIC COAST REGION (PROVINCES 5, 6, 7)

The following two sections describe methodology for evapotranspiration and water yield calculations for conditions found in the lower elevations of the Pacific Coast hydrologic provinces (5, 6, and 7), the Appalachian Mountains and Highlands hydrologic region (2), and the Gulf and Atlantic Coastal Plain and Piedmont hydrologic region (3).

Examples from three watersheds — Needle Branch, Coweeta (watershed #28), and Grant Memorial Forest (watershed #1) — have been developed to demonstrate application of the methodology and to document the procedure. Sample worksheets for each watershed provide summaries of the calculations performed by manipulation of the variables described.

The Pacific Coast region, a predominantly coniferous area, is a combination of climatic and physiographic conditions. Because snowpack development did not seem to be a significant factor in our simulations below 3,000 to 4,000 feet, the PROSPER model was applied. Above that elevation snowpack development was significant and, therefore, WATBAL was used. This discussion covers the lower elevation with a rain dominant regime only; for the higher elevations see the section concerned with snow dominated regions, and figure III.23 for the flow chart describing the appropriate methodology.

Appalachian Mountains and Highlands region consists primarily of mixed hardwoods, with some conifers. Precipitation is moderate, ranging from approximately 35-40 inches in some northern parts to nearly 100 inches in higher elevations to the south. Unlike the other two regions, latitude was a significant factor in quantifying the relationships in the Appalachian Mountains and Highlands region (2).

The Gulf and Atlantic coastal plain and Piedmont region is primarily a coniferous-deciduous forest mix with extensive plantations.

METHODOLOGY USED FOR DETERMINING EVAPOTRANSPIRATION AND WATER AVAILABLE FOR STREAMFLOW

The flow chart of the procedure for estimating evapotranspiration is presented in figure III.9. Evapotranspiration estimates are subtracted from precipitation data supplied by the user to estimate water that is potentially available for streamflow. Worksheets III.1 and III.2 have been constructed to follow the flow chart and to facilitate calculations. They accompany the illustrative examples at the end of this section.

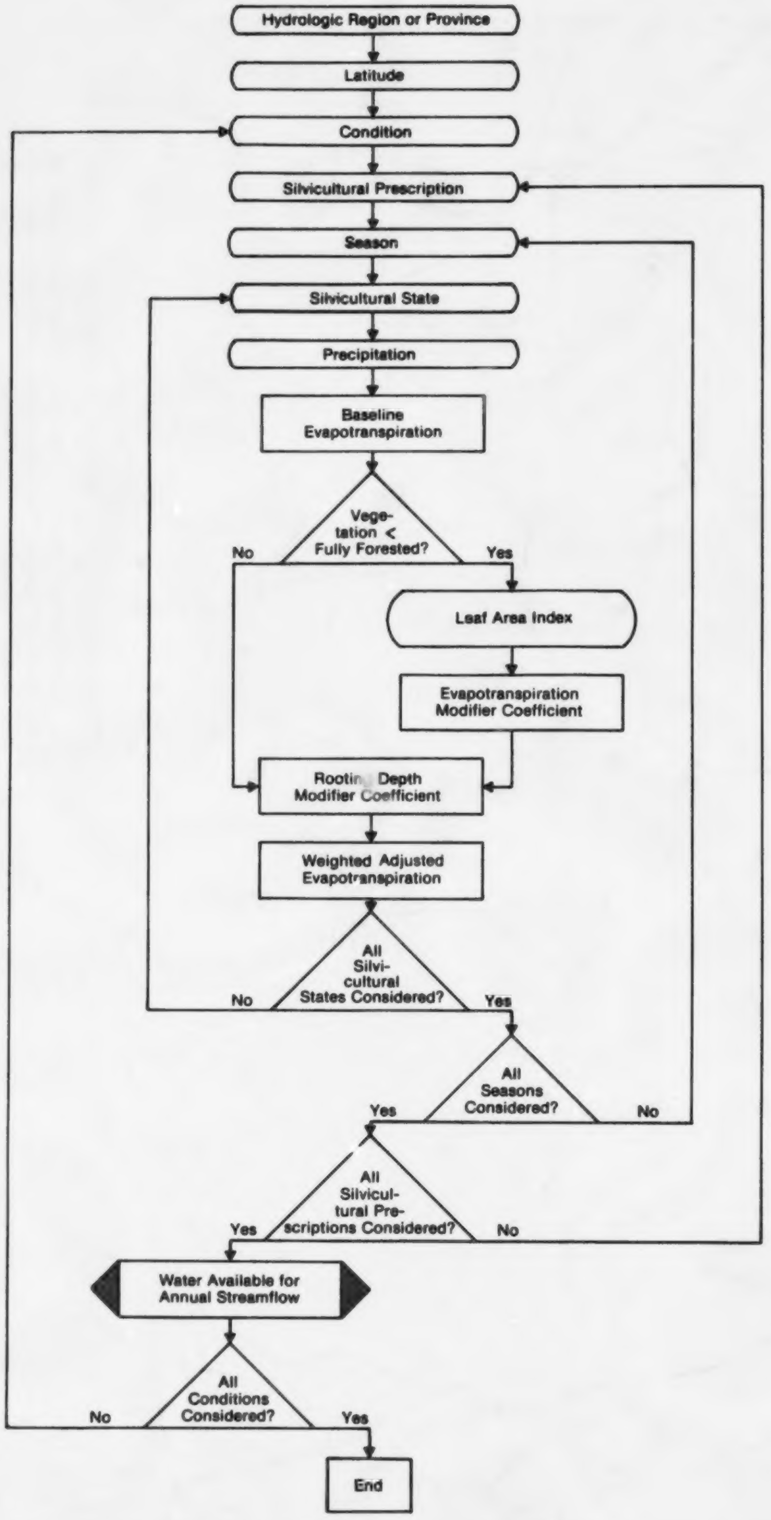
The following discussion keys on the components of the flow chart mentioned above and details each step in the analytical procedure. Also noted in the text are the worksheet columns in which the appropriate factor is entered.

HYDROLOGIC REGION OR PROVINCE

The region or province that characterizes the hydrologic regime for the watershed of interest must be decided. (fig. III.9a) Evapotranspiration calculations are based upon regional hydrologic relationships.

LATITUDE

Evapotranspiration loss was found to vary with latitude (item 4 on worksheets) as well as season for the Appalachian Mountains and Highlands region (2). Latitude, in this region, is analogous to the energy-aspect factor for snow dominated regions discussed in subsequent sections. The latitude of the drainage under evaluation must be provided.



Hydrologic Region or Province
Latitude
Condition
Silvicultural Prescription
Season
Silvicultural State
Precipitation
Baseline Evapotranspiration
Vegetation < Fully Forested?
No
Yes
Leaf Area Index
Evapotranspiration Modifier Coefficient
Rooting Depth Modifier Coefficient
Weighted Adjusted Evapotranspiration
All Silvicultural States Considered?
No
Yes
All Seasons Considered?
Yes
No
All Silvicultural Prescriptions Considered?
Yes
No
Water Available for Annual Streamflow
All Conditions Considered?
No
Yes
End

Figure III.9—Flow chart of methodology for determining evapotranspiration and water available for annual streamflow in rainfall dominated regions.

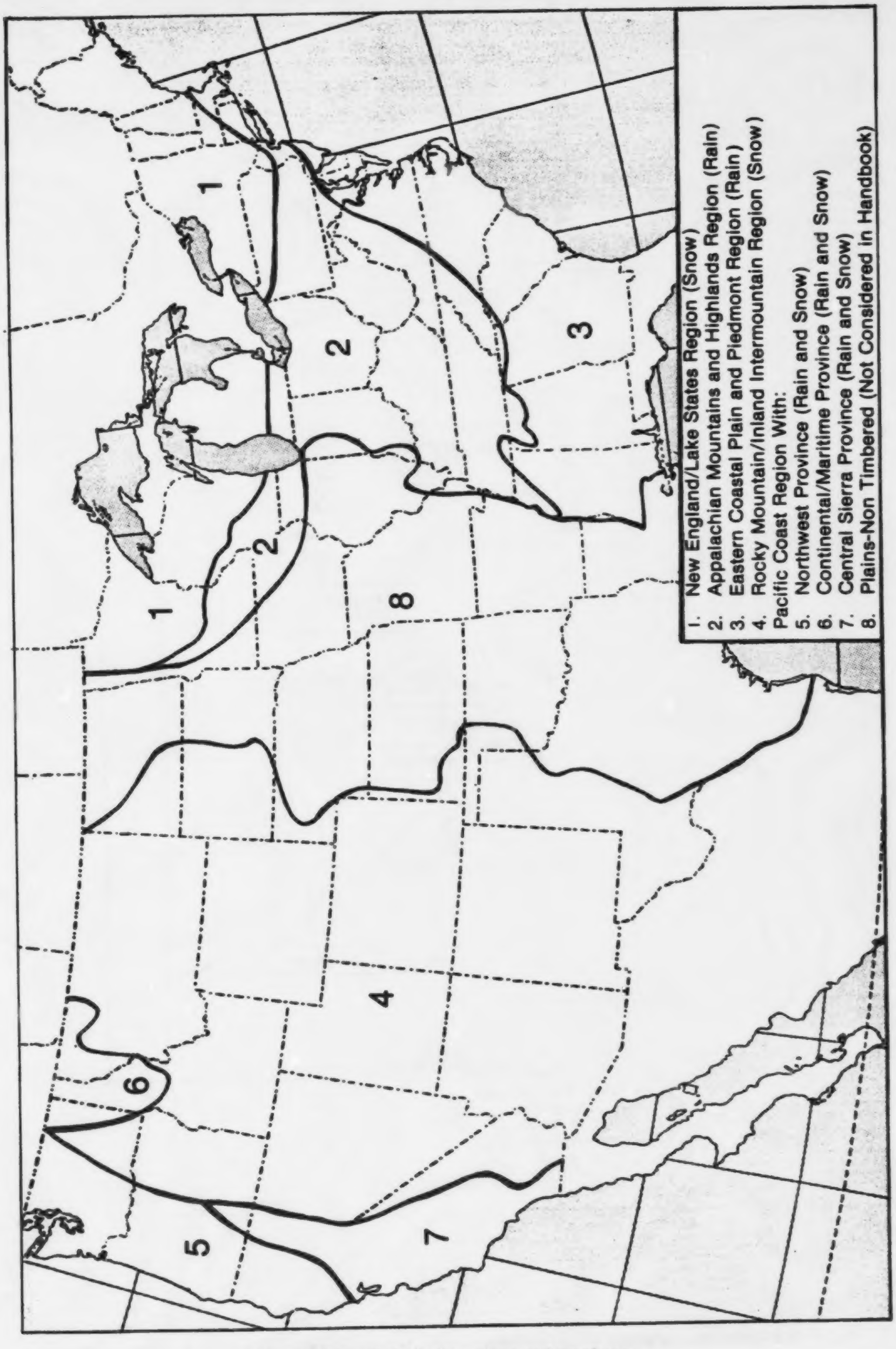

1. New England/Lake States Region (Snow)
2. Appalachian Mountains and Highlands Region (Rain)
3. Eastern Coastal Plain and Piedmont Region (Rain)
4. Rocky Mountain/Inland Intermountain Region (Snow)
Pacific Coast Region With:
5. Northwest Province (Rain and Snow)
6. Continental/Maritime Province (Rain and Snow)
7. Central Sierra Province (Rain and Snow)
8. Plains-Non Timbered (Not Considered in Handbook)
1
2
3
1
2
8
4
6
5
7

Figure III.9a—Hydrologic regions and provinces.

CONDITION

Calculations of evapotranspiration and water available for streamflow are made separately for each watershed condition (baseline, existing, proposed). Condition applies to the entire watershed, and the procedure (as flow charted) loops to this point after evapotranspiration and water available for streamflow have been calculated for each successive condition.

SILVICULTURAL PRESCRIPTION

For each condition, divide the watershed or management unit into segments based on uniformity of vegetation, soils and other factors defined for application of the silvicultural prescription. The prescription should be uniform for each segment or subwatershed and may be uniform for the entire watershed. Similarly, the silvicultural prescription can be uniform (i.e., forested) for one condition (existing) and varied (clearcut, thinned) for another (post-activity). Silvicultural prescription designations allow flexibility to subdivide the watershed into subunits based on significant silvicultural or hydrological characteristics of either the site or the prescriptions. This implies subdivision based not only on silvicultural practice, but also on uniform soil depth, aspect, and vegetation.

SEASON

Because the modeling effort is strongest on a seasonal or annual basis, four seasons were selected to express the relationships in these regions. Summer is represented by June, July, and August; fall by September, October, and November; winter by December, January, and February; and spring by March, April, and May. The procedure is looped so that all activities within a prescription are summed for that season.

SILVICULTURAL STATE

In many cases the watershed or subwatershed may be characterized as a uniform compartment, especially in the pre-treatment condition, due to similarity of such characteristics as vegetation, soils, and climate. However, the management prescription may require several practices or treatments to be applied to the compartment. When this is done, the post-treatment situation may result in different degrees of vegetative cover (silvicultural states) within each prescription.

Evapotranspiration estimates are made for each silvicultural state (items 6 and 7). Silvicultural state or treatment designations are chosen to group treatment areas of the watershed or watershed subunit that are similar in hydrologic response. Hydrologic response is related to the type and quantity of vegetation at a site and to such physical factors such as slope, soil texture, solar radiation, and precipitation regime. In rainfall dominated regions, leaf area index (LAI) is a major criterion for treatment delineation (see below).

The procedure is looped so that each silvicultural state is considered individually by season and prescription.

PRECIPITATION

Precipitation (item 10) for the season under evaluation must be supplied. This estimate may be based on actual onsite measurements or taken from other sources. Depending on the objectives, values may represent long-term averages or extremes.

BASELINE EVAPOTRANSPIRATION

An estimate of the simulated evapotranspiration for each region can be obtained from figure III.10 (Pacific Coast provinces-low elevation); figure III.11 (Appalachian Mountains and Highlands);

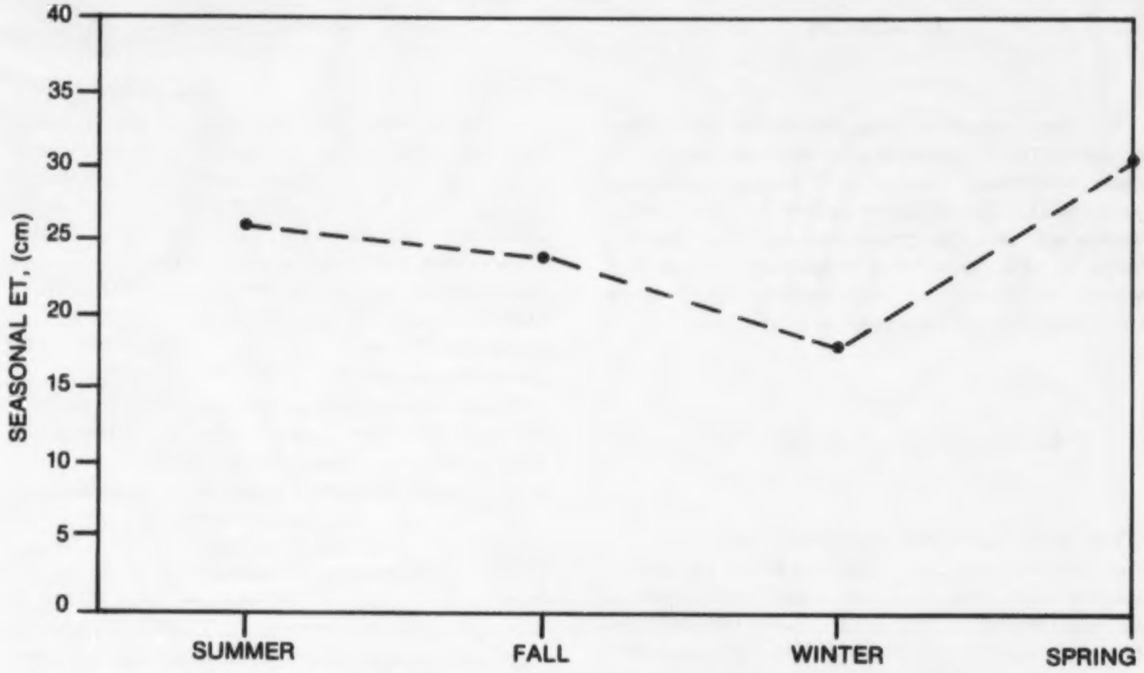


Figure III.10—Simulated seasonal evapotranspiration for the Pacific Coast hydrologic provinces—Northwest (5), Continental Maritime (6), and Central Sierra (7).

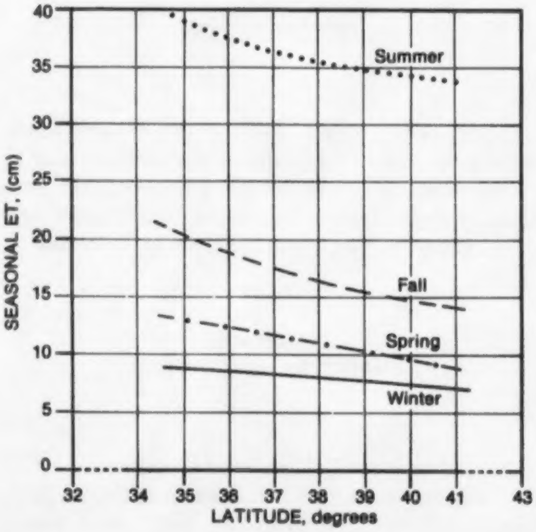


Figure III.11.—Average evapotranspiration for the Appalachian Mountain and Highlands hydrologic region (2) by latitude.

and figure III.12 (Eastern Coastal Plain and Piedmont). Estimates of monthly or seasonal evapotranspiration may also be obtained from other sources if site specific information is available. Site specific estimates improve subsequent estimates of change and thus enhance the evaluation.

The values provided represent the simulated evapotranspiration losses, by season, for the conditions which existed in the years simulated. These usually differ from estimates of potential evapotranspiration using conventional empirical techniques. A seasonal estimate of baseline evapotranspiration can be obtained directly from figures III.10, III.11, or III.12 by season; or they can be obtained from other sources if another estimate is more correct for the site in question.

Unlike the snow pack dominant regions, the simulations did not show any direct relationship between precipitation amount and evapotranspiration losses. Precipitation throughout the three regions under discussion is generally adequate to maintain near potential evapotranspiration rates.

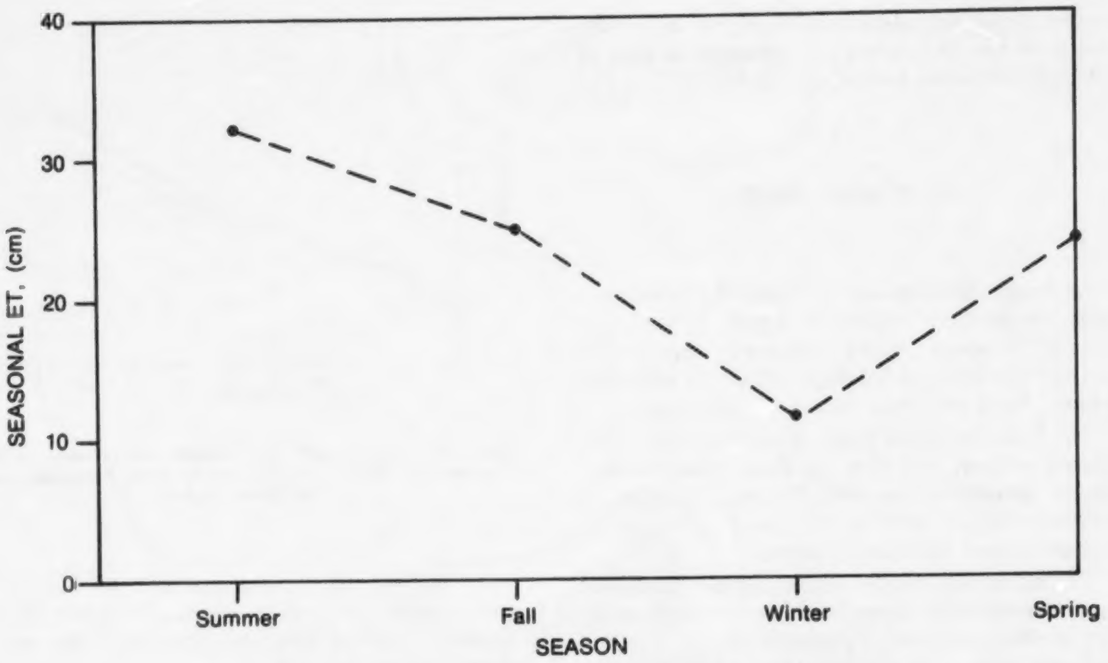


Figure III.12.—Seasonal average evapotranspiration for the Eastern Coastal Plain and Piedmont hydrologic region (3).

This does not mean that evapotranspiration does not vary with precipitation. It does mean that the state-of-the-art and the models used are such that in the rainfall regions, it is not possible to give a predictive technique for evaluating the impact of variations in precipitation on evapotranspiration losses.

There has also been much concern about both the effect of aspect on baseline evapotranspiration and its post-treatment changes. There is only one experimental observation isolating this effect (Swift and others 1975). PROSPER, the model used in hydrologic regions 2 and 3, and hydrologic provinces 5, 6, and 7, was not sensitive to simulating aspect effects and detected only a minor shift. Transpiration was about 5 percent greater on south facing aspects than on north facing aspects for baseline conditions and about 10 percent greater than on north facing aspects for the lower leaf area index (post-silvicultural activity) levels. In effect, the expected response in terms of increased flow would be slightly greater on north slopes than south, but the simulations did not indicate an effect even closely approximating the level observed by Swank and Swift (1975). Simulating aspect differences should also include effects of differing soils, vegetal complexes, and precipitation. If these were included, the differences would be greater than that for energy alone as aspect differences imply more than just energy differences.

Once the baseline ET values have been obtained from figures III.10 to III.12, it must be determined if the silvicultural state requires an adjustment in ET for changes in vegetative cover.

VEGETATION < FULLY FORESTED?

If vegetation for the silvicultural state under consideration is less than the fully forested baseline condition, modifier coefficients are used to adjust evapotranspiration accordingly. (Modifier coefficients will be discussed shortly.) If vegetation is in the fully forested baseline condition, no evapotranspiration adjustments are necessary, although a site specific adjustment may be necessary for rooting depth differences. Therefore, if dealing with baseline conditions, the analysis moves to the rooting depth considerations. If vegetal modification from baseline exists or is planned as part of this step, continue to leaf area index.

LEAF AREA INDEX

Leaf area index is used to obtain the evapotranspiration modifier coefficient which, in turn, adjusts ET to above ground vegetation conditions. If the leaf area index (LAI) (item 13) for the site is unknown, basal area may be used to estimate it.

The leaf area index (LAI) is used to index transpiring surface, and it is the ratio of leaf surface area to ground surface area. Rather than indexing transmissivity, it indexes the area of the major intercepting and transpiring surface.

The model used for the rainfall regions simulated evapotranspiration losses based on the leaf area index of the watershed. Estimates for the baseline leaf area index (LAI) used in the local calibrations came from scientists at each of the representative installations. In many cases it was measured; in other cases it was an estimate based on experience. If the necessary information is not available, basal area (BA) must be converted to leaf area index. Basal area should be readily available since it is used for planning most silvicultural activities.

Because of the complexity of basal area-leaf area index relationships and present inability to quantify them, it is strongly recommended that a local expert be contacted to obtain estimates for existing and proposed conditions for each treatment. If this is impossible, the curves for hardwoods and conifers provided in the following figures can be used to provide a first approximation. Complete hydrologic utilization is simulated whenever leaf area index exceeds 5 or 6, so the errors associated with estimating the upper levels of LAI are probably not too great.

Figure III.13 represents a first approximation of the basal area-leaf area index relation for reductions in a mature hardwood forest and the regrowth curve, assuming the site was cleared.

To perform a time series or recovery evaluation, one would treat the post-silvicultural activity evaluation as baseline and work backwards by estimating LAI for various time intervals along the regrowth curve.

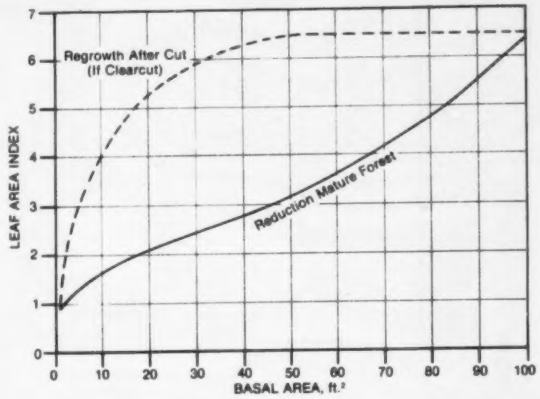


Figure III.13.—Leaf area index-basal area relationship for hardwood stands in the Appalachian Mountain and Highlands region.

A preliminary estimate of the LAI/BA relationship for conifers appears in figure III.14. Because of lack of data there was no attempt to express a regrowth curve.

Once the LAI for the silvicultural state under consideration has been estimated, the appropriate ET modifier coefficient can be determined.

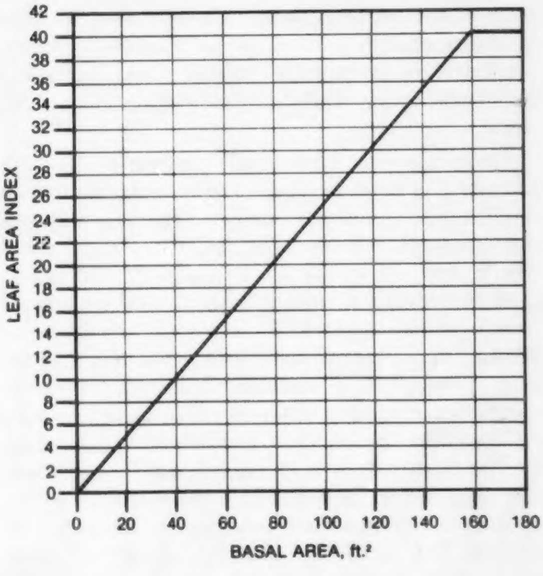


Figure III.14.—Leaf area index-basal relationship for conifer stands in the Appalachian Mountain and Highlands region.

ET MODIFIER COEFFICIENT

The appropriate modifier coefficient (item 14) that needs to be applied to the baseline evapotranspiration estimate (item 11) can be determined by entering the appropriate LAI into figures III.15 through III.17. This will adjust the estimate to on-site conditions for various leaf area index levels. Figures III.15 through III.17 represent the relative reduction in evapotranspiration which occurs for various reductions in leaf area index. In a later computational step, baseline ET will be multiplied by the ET modifier coefficient and other factors to estimate the "adjusted ET."

ROOTING DEPTH MODIFIER COEFFICIENT

The hydrologic model, PROSPER, is sensitive to "rooting depth" (item 15) in that it responds to the defined soil depth from which soil water can be extracted. Since PROSPER is a physically based, process oriented model, it integrates the interaction between available soil water (water between field capacity and wilting point), precipitation, and energy. By altering the specified rooting depth, one can alter the simulated evapotranspiration. Rooting depth was altered for various simulations from average to shallow (half the average) to deep (twice the average). It is recognized that all roots are neither contained in nor draw water from the upper 1.5, 3, or 6 feet of the soil mantle, and that no hydrologic model will simulate the true effect of root distribution under all climatic regimes. What is simulated by altering "rooting depth" is the relative response in evapotranspiration to changes in soil depth or soil water availability.

In general, annual evapotranspiration decreases with shallow soil and increases as soil depth or moisture availability increases. Beyond a depth of 6 feet (approximately 10 to 12 inches of available water), increasing the depth had little detectable effect. Thus, given the precipitation amounts and

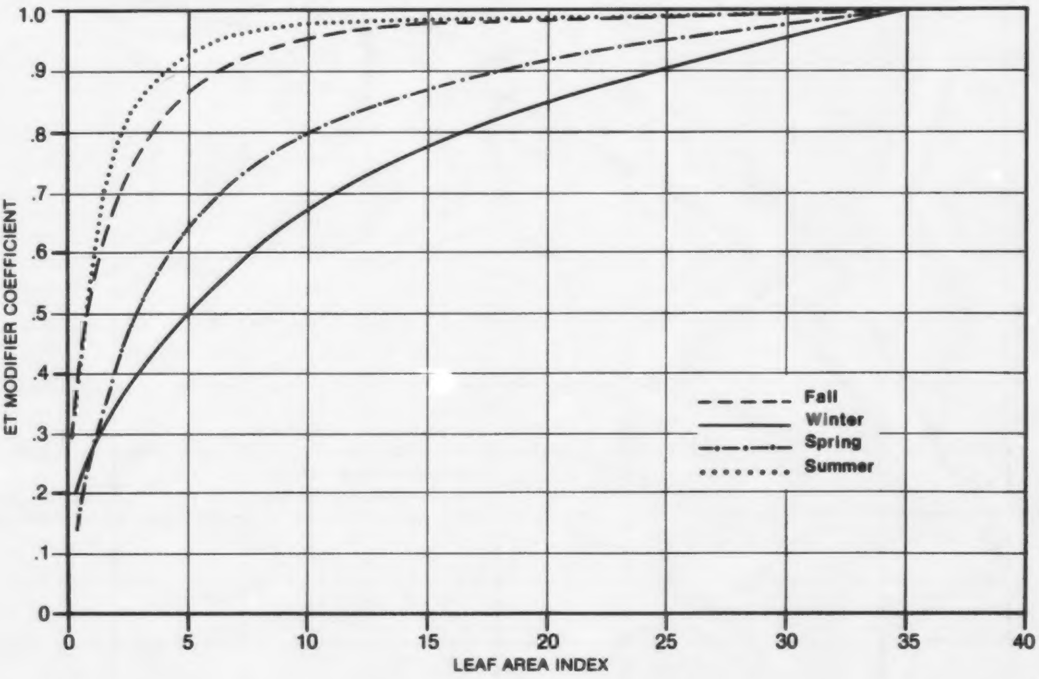


Figure III.15.—Evapotranspiration modifier coefficients, for all seasons, for the Pacific Coast hydrologic provinces—Northwest (5), Continental/Maritime (6), and Central Sierra (7).

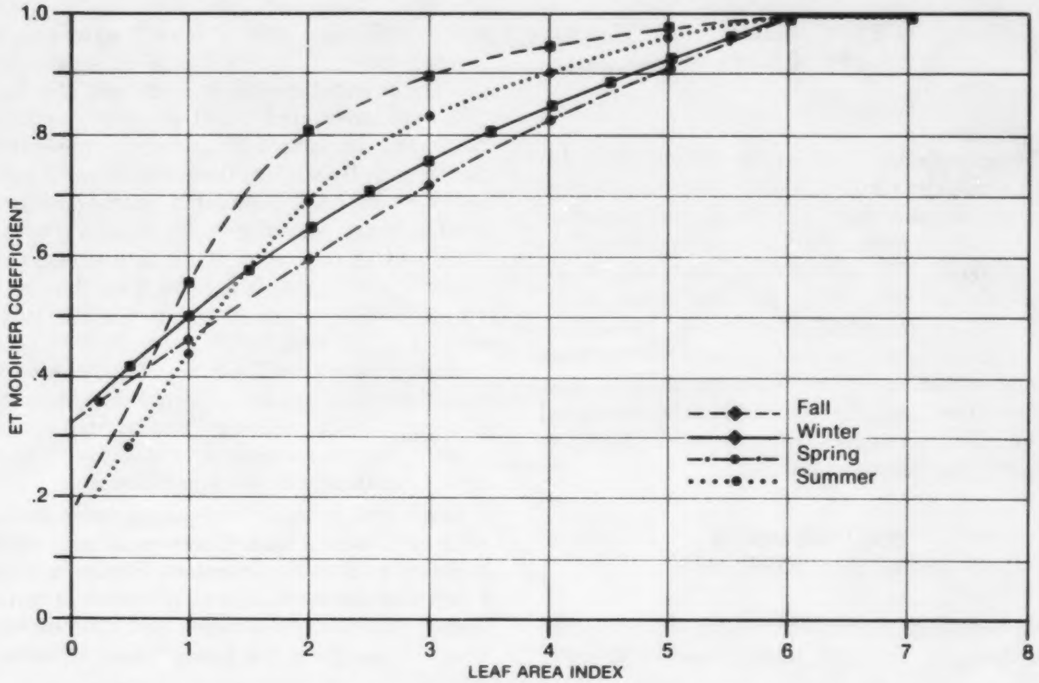


Figure III.16.—Evapotranspiration modifier coefficients, for all seasons, for the Appalachian Mountains/Highlands hydrologic region (2).

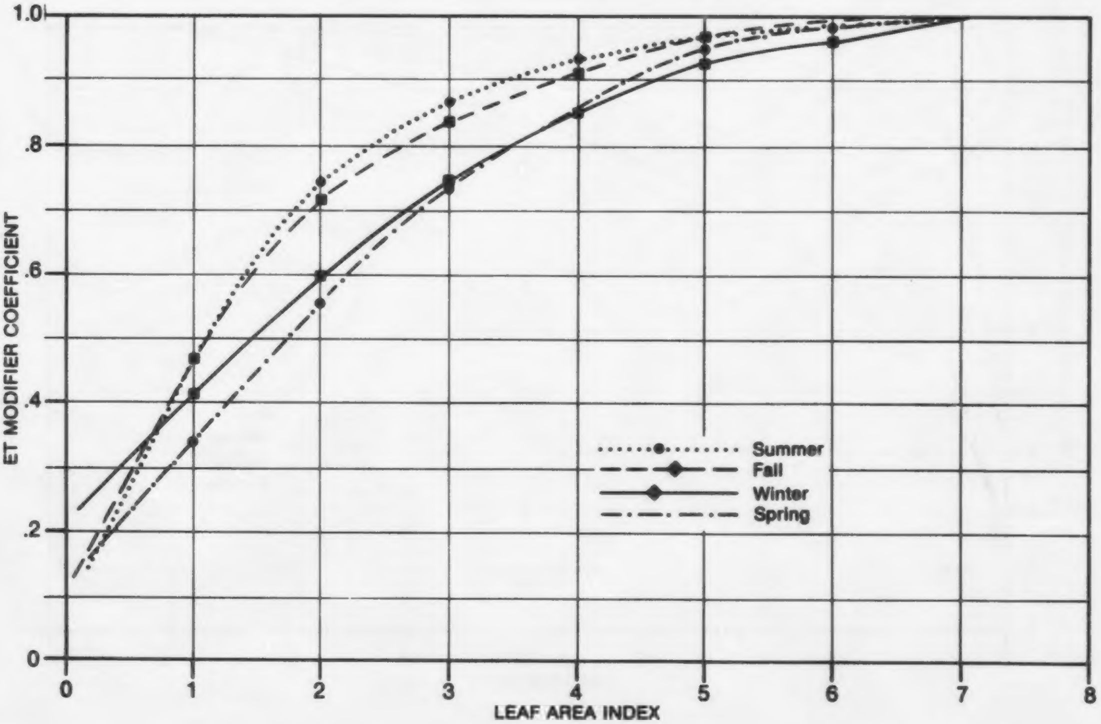


Figure III.17.—Evapotranspiration modifier coefficients, for all seasons, for the Eastern Coastal Plain and Piedmont hydrologic region (3).

distribution for the station years simulated by PROSPER, evapotranspiration occurred at a rate controlled mostly by available energy once the soil was 6 to 8 feet deep or moisture availability exceeded 10 to 12 inches. This does not imply roots do not go deeper or that they will not extract water from greater depths, especially during drought years.

Under dry conditions, moisture availability may be limiting in the upper soil layer where the majority of roots occur. The plant will then depend on greater proportional extraction by roots at much greater depths.

The simulations indicated that local variation in relative rooting depth or depth available for root penetration alters the evapotranspirational loss, a fact quantified but not predictable (based on experience or research). As the relative rooting depth decreases, the available water (soil moisture) decreases, thus limiting evapotranspiration. For most of the hydrologic regions, the average rooting depth was considered to be about 3 to 4 feet (6 feet for the southern Appalachians and Gulf and Atlantic coasts).

Figures III.18, III.19, and III.20 depict the relative adjustment in evapotranspiration that was simulated as a function of changing the relative rooting depth. Average soil depths were established at 4 feet in the east (Appalachian Highlands), 3 feet in the west (Pacific Northwest), and 6 feet in the south. Shallow soils were considered to be one-half the average, while deep soils were twice the average. Beyond 6 feet rooting depth, no significant effect on transpiration with increasing rooting depth was produced.

An estimate of the average soil depth for the silvicultural prescription unit and figures III.18 through III.20 are needed to estimate the rooting depth modifier for the site. This is done for all prescriptions as the coefficient is used to further correct ET for onsite conditions.

WEIGHTED ADJUSTED EVAPOTRANSPIRATION

Multiplication of baseline ET (item 11) by the ET modifier coefficient (item 14, which equals 1 for baseline conditions) and the rooting depth modifier coefficient (item 15) will yield an estimate of the adjusted evapotranspiration. Further multiplication by the area of the silvicultural state (expressed as a decimal percent of the watershed area (item 9)) area weights the ET. It is entered as item 16 on the worksheets and is calculated separately for each silvicultural state by season, for each prescription. In the form of an equation:

$$ET_A = ET_B \times C_{ET} \times RD \times \text{Silvicultural State Area} \quad (III.4)$$

where:

ET_A = Site specific seasonal evapotranspiration loss for a specified silvicultural activity for either the existing or proposed condition

ET_B = Seasonal baseline evapotranspiration by latitude, if appropriate, derived from either figure III.10, III.11, or III.12 (or some other source)

C_{ET} = Evapotranspiration modifier coefficient taken, by season, from figures III.15 — III.17 for a specified leaf area index

Silvicultural State Area = Area of silvicultural state as a decimal % of watershed area

RD = Rooting depth modifier coefficients, from figures III.18, III.19, or III.20.

Figures III.15 to III.17 provide the capability of estimating evapotranspiration, corrected for leaf area index and adjusted, if necessary, for either the existing or proposed condition. Figures III.18 to III.20 provide root depth adjustments.

ALL SILVICULTURAL STATES CONSIDERED

The calculations are now complete for one silvicultural or vegetal state. The loop is repeated until all silvicultural states (item 7) are considered by season.

ALL SEASONS CONSIDERED?

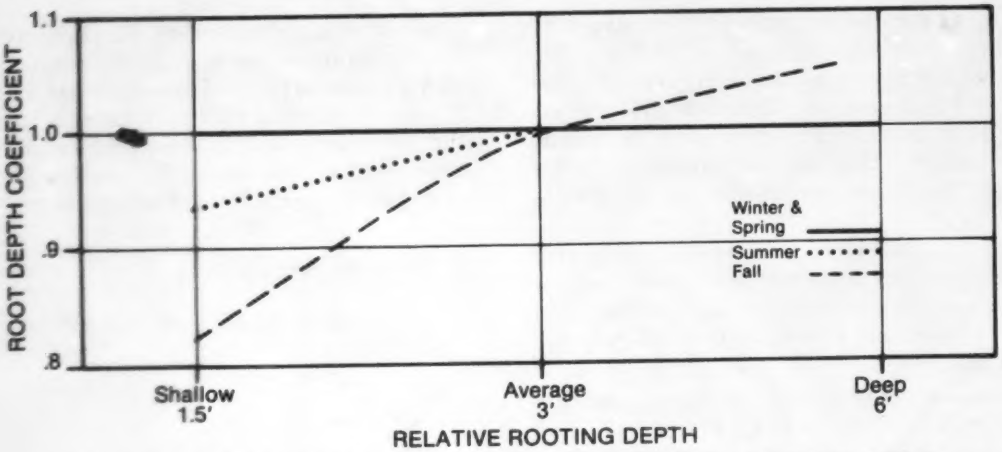


Figure III.18.—Root depth modifier coefficients, by season, for the Pacific Coast hydrologic provinces—Northwest (5), Continental/Maritime (6), and Central Sierra (7).

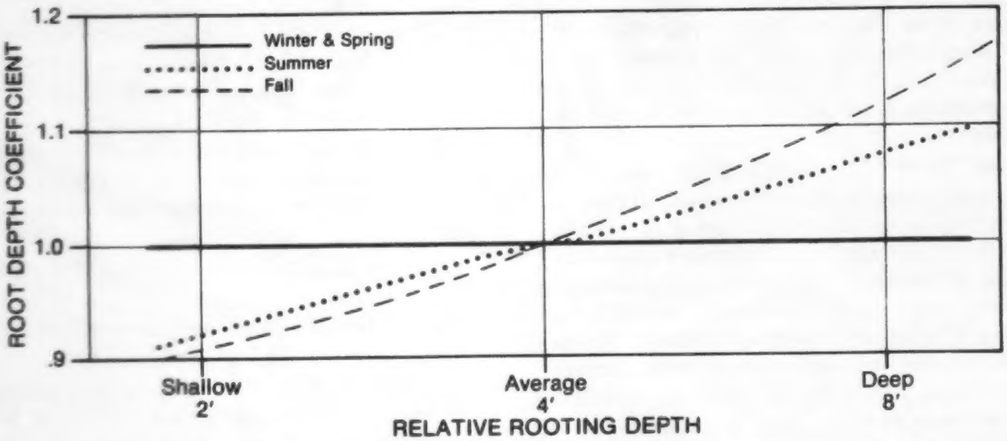


Figure III.19.—Root depth modifier coefficients, by season, for the Appalachian Mountains and Highlands hydrologic regions (2).

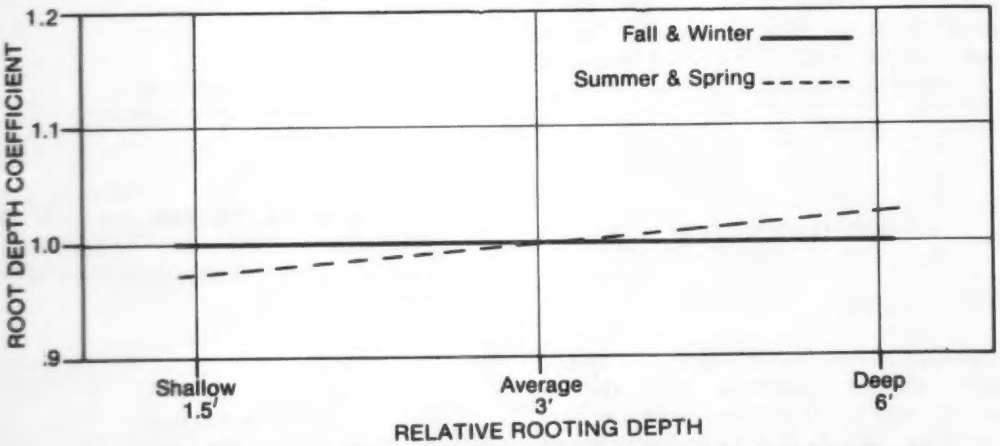


Figure III.20.—Root depth modifier coefficients, by season, for the Eastern Coastal Plains and Piedmont hydrologic regions (3).

Evapotranspiration calculations are performed for all silvicultural states by season and for all seasons by prescription. At this point all the necessary adjustments to ET for differing states for one season and one watershed prescription have been made. The loop is repeated until all seasons (item 5) have been considered.

ALL SILVICULTURAL PRESCRIPTIONS CONSIDERED?

At this point all the calculations for state by season for one prescription have been made. The loop is continued until all prescriptions for the condition are completed.

The difference between precipitation and evapotranspiration is water available for streamflow, assuming soil moisture requirements are negligible. Water available for streamflow is an onsite estimate since routing through the soil mantle has not been simulated.

Streamflow, by prescription, is estimated in the following manner: adjusted seasonal evapotranspiration for each state in the prescription (item 16) is summed, by season, to yield adjusted seasonal evapotranspiration (item 17) for the prescription. Item 17 is subtracted from the seasonal precipitation (item 10) to yield a seasonal estimate of water available for streamflow (item 18) for the prescription. Seasonal values for both evapotranspiration (item 17) and streamflow (item 18) are summed to estimate annual values (items 19 and 20).

If the watershed delineation consists of only one prescription, the above values represent watershed values. If the watershed consists of more than one prescription, the values will have to be area weighted and summed over prescription.

WATER AVAILABLE FOR ANNUAL STREAMFLOW

Worksheets III.1 and III.2 are useful in arriving at estimates of ET and streamflow, on a seasonal and annual basis, by prescription. Because of the variable nature of watershed division, no worksheets have been established for watershed summations. Obviously if the watershed is considered uniform, with only one prescription designation, then the prescription summary is the watershed summary.

If more than one prescription (or unit) is established, they must be summed to get annual flow using the following relationship:

$$Q_w = \sum_{P=1}^{i} \left(Q_p \times \frac{\text{Prescription Area (P)}}{\text{Watershed Area}}\right) \qquad \text{(III.5)}$$

where:

Q_W = Water available for annual streamflow for the entire watershed
Q_P = Water available for annual streamflow for the prescription.
i = Number of prescriptions
Prescription Area (P) = Area of prescription (P)
Watershed Area = Area of entire watershed

In like manner, the user can substitute the appropriate ET values into the equation to get an estimate of watershed ET. By the same token, summation using seasonal rather than annual values will yield seasonal summaries.

ALL CONDITIONS CONSIDERED?

The procedure is structured so that evapotranspiration and water available for streamflow for one condition must be calculated before evapotranspiration and water available for streamflow for another condition is calculated. The procedure returns to the "Condition" step until all conditions have been considered.

END

Evapotranspiration and water available for streamflow calculations are complete. Values for existing and proposed conditions have been calculated. The next step is construction of pre- and post-silvicultural activity 7-day flow duration curves.

Examples: Determining Evapotranspiration And Water Available For Streamflow

Using figures III.9a to III.20, a technique for determining pre- and post-silvicultural activity evapotranspiration losses has been presented. Specific examples of the procedure follow. The item numbers in parentheses relate to column numbers in the appropriate worksheets.

WORKSHEET III.1

Water available for streamflow for the existing condition in rainfall dominated regions

(1) Watershed name Needle Branch (2) Hydrologic region 5 (3) Total prescription area (acres) 237 (4) Latitude ______

Season name/ dates (5)	Silvicultural prescription		Area		Precipi- tation (cm) (10)	Baseline ET (cm) (11)	Basal area (ft²/ac) (12)	Leaf area index (13)	ET modifier coef. (14)	Rooting depth modifier coef. (15)	Weighted adjusted ET (cm) (16)	Weighted adjusted seasonal ET (cm) (17)	Water available for sea- sonal stream- flow (cm) (18)
	Compartment (6)	Silvicultural state (7)	Acres (8)	Per- cent (9)									
Fall 9/1 - 11/30	Unimpacted	Forested	237	1.000	31.2	24		40	1.0	1.0	24.0		
	Impacted												
	Total for season		237	1.000	31.2						24.0	24.0	7.2
Winter 12/1 - 2/28	Unimpacted	Forested	237	1.000	128.1	18		40	1.0	1.0	18.0		
	Impacted												
	Total for season		237	1.000	128.1						18.0	18.0	110.1
Spring 3/1 - 5/31	Unimpacted	Forested	237	1.000	62.1	30.5		40	1.0	1.0	30.5		
	Impacted												
	Total for season		237	1.000	62.1						30.5	30.5	31.6
Summer 6/1 - 8/31	Unimpacted	Forested	237	1.000	11.4	26		40	1.0	1.0	26.0		
	Impacted												
	Total for season		237	1.000	11.4						26.0	26.0	-14.6
(19) Annual ET (cm)												98.5	
(20) Water available for annual streamflow (cm)													134.3

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in text.
(3),(4)	Supplied by user.
(5)	Seasons for rainfall dominated regions are fall (September, October, November), winter (December, January, February), spring (March, April, May), and summer (June, July, August).
(6)	The unimpacted compartment includes areas not affected by the silvicultural prescription. The impacted compartment includes areas affected by the silvicultural prescription.
(7)	Areas of similar hydrologic response as identified and delineated by vegetation or silvicultural state.
(8)	Supplied by user.
(9)	Column (8) ÷ item (3).
(10)	Measured or estimated by the user.
(11)	From figures III.10 to III.12; or user supplied.
(12)	Supplied by user. Unnecessary if leaf area index is known.
(13)	From figures III.13 and III.14; or user supplied.
(14)	From figures III.15 to III.17.
(15)	From figures III.18 to III.20.
(16)	Calculated as (11) x (14) x (15) x (9); or user supplied.
(17)	Seasonal sum of column (16).
(18)	Column (10) - column (17).
(19)	Sum of column (17).
(20)	Sum of column (18).

WORKSHEET III.2

Water available for streamflow for the proposed condition in rainfall dominated regions

(1) Watershed name Needle Branch (2) Hydrologic region 5 (3) Total prescription area (acres) 237 (4) Latitude ______

Season name/ dates (5)	Silvicultural prescription: Compartment (6)	Silvicultural prescription: Silvicultural state (7)	Area: Acres (8)	Area: Per-cent (9)	Precipi-tation (cm) (10)	Baseline ET (cm) (11)	Basal area (ft²/ac) (12)	Leaf area index (13)	ET modifier coef. (14)	Rooting depth modifier coef. (15)	Weighted adjusted ET (cm) (16)	Weighted adjusted seasonal ET (cm) (17)	Water available for seasonal streamflow (cm) (18)
Fall 9/1 - 11/30	Unimpacted												
	Impacted	Clearcut	237	1.000	31.2	24		1	.54	1.0	13.0		
	Total for season		237	1.000	31.2						13.0	13.0	18.2
Winter 12/1 - 2/28	Unimpacted												
	Impacted	Clearcut	237	1.000	128.1	13		1	.38	1.0	5.0		
	Total for season		237	1.000	128.1						5.0	5.0	123.1
Spring 3/1 - 5/31	Unimpacted												
	Impacted	Clearcut	237	1.000	62.1	30.5		1	.27	1.0	8.2		
	Total for season		237	1.000	62.1						8.2	8.2	53.9
Summer 6/1 - 8/31	Unimpacted												
	Impacted	Clearcut	237	1.000	11.4	26.0		1	.55	1.0	14.3		
	Total for season		237	1.000	11.4						14.3	14.3	-2.9
(19) Annual ET (cm)												40.5	
(20) Water available for annual streamflow (cm)													192.3

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in text.
(3),(4)	Supplied by user.
(5)	Seasons for rainfall dominated regions are fall (September, October, November), winter (December, January, February), spring (March, April, May), and summer (June, July, August).
(6)	The unimpacted compartment includes areas not affected by the silvicultural prescription. The impacted compartment includes areas affected by the silvicultural prescription.
(7)	Areas of similar hydrologic response as identified and delineated by vegetation or silvicultural state.
(8)	Supplied by user.
(9)	Column (8) ÷ item (3).
(10)	Measured or estimated by the user.
(11)	From figures III.10 to III.12; or user supplied.
(12)	Supplied by user. Unnecessary if leaf area index is known.
(13)	From figures III.13 and III.14; or user supplied.
(14)	From figures III.15 to III.17.
(15)	From figures III.18 to III.20.
(16)	Calculated as (11) x (14) x (15) x (9); or user supplied.
(17)	Seasonal sum of column (16).
(18)	Column (10) - column (17).
(19)	Sum of column (17).
(20)	Sum of column (18).

Example 1. The Needle Branch Watershed Worksheets III.1 and III.2 (Needle Branch)

In this first example, for the Pacific Coast provinces-low elevation, Dennis Harr (personal communication, 1977) provided data from Needle Branch of the Alsea Watershed in western Oregon. The baseline LAI of 40 was reduced to an average of 1 for the first 3 years after silvicultural activity. Rooting depth was average (4 feet) and an aspect correction was made (effect assumed=1) for the north facing watershed.

The first step in the procedure is to estimate the baseline potential evapotranspiration.

For the pre-treatment condition [see worksheets III.1 and III.2 (Needle Branch)], the baseline evapotranspiration by season (from fig. III.10) is shown in the summary below; the precipitation data in the example were taken from the data base record for the H. J. Andrews Experimental Forest. It should be noted that the watershed has been divided into one silvicultural prescription and one silvicultural state both before (forested) and after (clearcut) treatment.

Season (Item 5)	Precipitation (Item 10)	Baseline ET (Item 11)
Summer	11.6 cm (6.5 in)	26 cm (10.2 in)
Fall	31.2 cm (12.3 in)	24 cm (9.5 in)
Winter	128.1 cm (50.4 in)	18 cm (7.1 in)
Spring	82.1 cm (24.4 in)	30.5 cm (12 in)
Total	232.8 cm (91.6 in)	98.5 cm (38.8 in)

For the pre-treatment (existing) condition, the annual evapotranspiration loss is estimated at 98.5 cm or 38.8 inches. In this example the precipitation is 91.6 inches, so the water potentially available for streamflow is 52.8 inches.

For the post-activity conditions, the following estimates are presented:

Season (Item 5)	Baseline ET (Item 11)	ET modifier (Item 14)	Root depth modifier (Item 15)	Post-silvicultural activity ET (col 1 x 2 x 3)
	(1)	(2)	(3)	(4)
Summer	26 cm	0.55	1.0	14.3 cm
Fall	24 cm	0.54	1.0	13.0 cm
Winter	18 cm	0.28	1.0	5.0 cm
Spring	30.5 cm	0.27	1.0	8.2 cm
Total	98.5 cm			40.5 cm

The potential change in evapotranspiration is 98.5 cm minus 40.5 cm or 58.0 cm (22.8 inches) of potential increase in flow. The observed change averaged 19.8 inches for the 3-year study period. The total potential flow for the post-activity period is 52.8 baseline inches and 22.8 inches change or 75.6 inches total.

Example 2. The Coweeta Watershed Worksheets III.1 And III.2 (Coweeta)

For the Appalachian Mountains and Highlands, Hewlett and Douglass (1968) reported on a management demonstration on a 356-acre watershed at Coweeta Hydrologic Laboratory near Franklin, North Carolina. Of the 356 acres, 180 were clearcut, 92 were thinned, and the remainder left uncut. The expected net change in evapotranspiration would be estimated in the following manner.

Again, the watershed is considered fairly uniform so only one silvicultural prescription has been defined for all 356 acres. For the pre-treatment condition, this also implies one silvicultural state — forested. For the post-treatment condition, three silvicultural states are implied — forested, thinned, and clearcut.

For existing conditions, the baseline leaf area index for hardwoods at Coweeta is about 6 (Swift and others 1975). The residual leaf area index on the clearcut portion was 2, while that on the thinned portion was 3 (Patric and Hewlett, personal communication). The baseline evapotranspiration, assuming a leaf area index of 6 (latitude of 35°) and using figure III.11, is shown in the summary below:

Season (Item 5)	Precipitation (Item 10)	Baseline ET (Item 11)
Summer	27.0 cm (10.6 in)	39.1 cm (15.4 in)
Fall	23.3 cm (9.2 in)	20.1 cm (7.9 in)
Winter	75.2 cm (29.6 in)	8.9 cm (3.5 in)
Spring	60.5 cm (23.8 in)	13.0 cm (5.1 in)
Annual	186.0 cm (73.2 in)	81.1 cm (31.9 in)

For the pre-treatment condition, the annual evapotranspiration loss is estimated as 81.1 cm or 31.9 inches (item 17). The precipitation estimate represents the average for the simulation years. Therefore, if the estimated evapotranspiration is 31.9 inches and the precipitation is 73.2 inches, the water potentially available for streamflow is 41.3 inches.

WORKSHEET III.1

Water available for streamflow for the existing condition in rainfall dominated regions

(1) Watershed name Coweeta (2) Hydrologic region 2 (3) Total prescription area (acres) 356 (4) Latitude 35°

Season name/ dates (5)	Silvicultural prescription		Area		Precipi- tation (cm) (10)	Baseline ET (cm) (11)	Basal area (ft²/ac) (12)	Leaf area index (13)	ET modifier coef. (14)	Rooting depth modifier coef. (15)	Weighted adjusted ET (cm) (16)	Weighted adjusted seasonal ET (cm) (17)	Water available for sea- sonal stream- flow (cm) (18)
	Compartment (6)	Silvicultural state (7)	Acres (8)	Per- cent (9)									
Fall 9/1 - 11/30	Unimpacted	Forested	356	1.000	23.3	20.1		6	1.0	1.0	20.1		
	Impacted												
	Total for season		356	1.000	23.3						20.1	20.1	3.2
Winter 12/1 - 2/28	Unimpacted	Forested	356	1.000	75.2	8.9		6	1.0	1.0	8.9		
	Impacted												
	Total for season		356	1.000	75.2						8.9	8.9	66.3
Spring 3/1 - 5/31	Unimpacted	Forested	356	1.000	60.5	13.0		6	1.0	1.0	13.0		
	Impacted												
	Total for season		356	1.000	60.5						13.0	13.0	47.5
Summer 6/1 - 8/31	Unimpacted	Forested	356	1.000	27.0	39.1		6	1.0	1.0	39.1		
	Impacted												
	Total for season			1.000	27.0						39.1	39.1	-12.1
(19) Annual ET (cm)												81.1	
(20) Water available for annual streamflow (cm)													104.9

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in text.
(3),(4)	Supplied by user.
(5)	Seasons for rainfall dominated regions are fall (September, October, November), winter (December, January, February), spring (March, April, May), and summer (June, July, August).
(6)	The unimpacted compartment includes areas not affected by the silvicultural prescription. The impacted compartment includes areas affected by the silvicultural prescription.
(7)	Areas of similar hydrologic response as identified and delineated by vegetation or silvicultural state.
(8)	Supplied by user.
(9)	Column (8) ÷ item (3).
(10)	Measured or estimated by the user.
(11)	From figures III.10 to III.12; or user supplied.
(12)	Supplied by user. Unnecessary if leaf area index is known.
(13)	From figures III.13 and III.14; or user supplied.
(14)	From figures III.15 to III.17.
(15)	From figures III.18 to III.20.
(16)	Calculated as (11) x (14) x (15) x (9); or user supplied.
(17)	Seasonal sum of column (16).
(18)	Column (10) - column (17).
(19)	Sum of column (17).
(20)	Sum of column (18).

WORKSHEET III.2

Water available for streamflow for the proposed condition in rainfall dominated regions

(1) Watershed name Coweeta (2) Hydrologic region 2 (3) Total prescription area (acres) 356 (4) Latitude 35°

Season name/ dates (5)	Silvicultural prescription		Area		Precipitation (cm) (10)	Baseline ET (cm) (11)	Basal area (ft²/ac) (12)	Leaf area index (13)	ET modifier coef. (14)	Rooting depth modifier coef. (15)	Weighted adjusted ET (cm) (16)	Weighted adjusted seasonal ET (cm) (17)	Water available for seasonal streamflow (cm) (18)
	Compartment (6)	Silvicultural state (7)	Acres (8)	Percent (9)									
Fall 9/1 - 11/30	Unimpacted	Forested	84	.236	23.3	20.1		6	1.00	1.0	4.74		
	Impacted	Clearcut	180	.506	23.3	20.1		2	.81	1.0	8.23		
		Thinned	92	.258	23.3	20.1		3	.90	1.0	4.67		
	Total for season		356	1.000	23.3						17.64	17.64	5.7
Winter 12/1 - 2/28	Unimpacted	Forested	84	.236	75.2	8.9		6	1.00	1.0	2.10		
	Impacted	Clearcut	180	.506	75.2	8.9		2	.65	1.0	2.93		
		Thinned	92	.258	75.2	8.9		3	.76	1.0	1.75		
	Total for season		356	1.000	75.2						6.78	6.8	68.4
Spring 3/1 - 5/31	Unimpacted	Forested	84	.236	60.5	13.1		6	1.00	1.0	3.07		
	Impacted	Clearcut	180	.506	60.5	13.1		2	.60	1.0	3.95		
		Thinned	92	.258	60.5	13.1		3	.72	1.0	2.41		
	Total for season		356	1.000	60.5						9.43	9.4	51.1
Summer 6/1 - 8/31	Unimpacted	Forested	84	.236	27.0	39.1		6	1.00	1.0	9.23		
	Impacted	Clearcut	180	.506	27.0	39.1		2	.69	1.0	13.65		
		Thinned	92	.258	27.0	39.1		3	.84	1.0	8.47		
	Total for season		356	1.000	27.0						31.35	31.4	-4.4
(19) Annual ET (cm)												65.2	
(20) Water available for annual streamflow (cm)													120.8

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in text.
(3),(4)	Supplied by user.
(5)	Seasons for rainfall dominated regions are fall (September, October, November), winter (December, January, February), spring (March, April, May), and summer (June, July, August).
(6)	The unimpacted compartment includes areas not affected by the silvicultural prescription. The impacted compartment includes areas affected by the silvicultural prescription.
(7)	Areas of similar hydrologic response as identified and delineated by vegetation or silvicultural state.
(8)	Supplied by user.
(9)	Column (8) ÷ item (3).
(10)	Measured or estimated by the user.
(11)	From figures III.10 to III.12; or user supplied.
(12)	Supplied by user. Unnecessary if leaf area index is known.
(13)	From figures III.13 and III.14; or user supplied.
(14)	From figures III.15 to III.17.
(15)	From figures III.18 to III.20.
(16)	Calculated as (11) x (14) x (15) x (9); or user supplied.
(17)	Seasonal sum of column (16).
(18)	Column (10) - column (17).
(19)	Sum of column (17).
(20)	Sum of column (18).

For post-treatment conditions, the estimates would be as follows:

(1) For the clearcut portion: leaf area index = 2; root depth = average; no aspect adjustment. [See worksheet III.2 (Coweeta).]

Season (item 5)	Baseline ET (item 11) (fig III.11)	ET modifier (item 14) (fig III.16)	Root modifier (item 15) (fig III.19)	Post-silvicultural activity ET (col 1 x 2 x 3)
	(1)	(2)	(3)	(4)
Summer	39 cm	0.69	1.0	26.9 cm
Fall	20 cm	0.81	1.0	16.2 cm
Winter	9 cm	0.65	1.0	5.8 cm
Spring	13 cm	0.60	1.0	7.8 cm
Total	81 cm			56.7 cm

(2) For the thinned portion: leaf area index = 3; root depth = average; no aspect correction. [See worksheet III.2 (Coweeta).]

Season (item 5)	Baseline ET (item 11) (fig. III.11)	ET modifier (item 14) (fig. III.16)	Root modifier (item 15) (fig. III.19)	Post-silvicultural activity ET (col 1 x 2 x 3)
	(1)	(2)	(3)	(4)
Summer	39	0.84	1.0	32.8 cm
Fall	20	0.90	1.0	18.0 cm
Winter	9	0.76	1.0	6.8 cm
Spring	13	0.72	1.0	9.4 cm
Total	81			67.0 cm

(3) For the managed but uncut portion: potential evapotranspiration is the same as the baseline condition.

To estimate the net silvicultural impact on evapotranspiration, the following procedure can be applied for either annual or seasonal post-silvicultural activity effect. It simply weights the relative effect of each management condition as shown in the table below:

Unit	Acres (item 8)	Area as % of total (item 9)	Unit potential evapotranspiration	Weighted unit evapotranspiration (area % × ET)
Clearcut	180	50.6	56.7 cm	28.7 cm
Thinned	92	25.8	67.0 cm	17.3 cm
Unmanaged	84	23.6	81.0 cm	19.1 cm
Total	356	100.0	---	65.1 cm

The pre-activity (baseline) annual evapotranspiration was 81 cm (31.9 in) for the watershed. The weighted post-activity evapotranspiration is estimated as 65.1 cm (25.6 in), and the change due to the proposed silvicultural activity is 6.3 inches. The water potentially available for flow following the activity increases 6.3 inches from 41.3 to 47.6 inches.

The observed change in flow (Hewlett and Douglass 1968) in the watershed studied was 6.2 inches. It must be remembered that the leaf area estimates for the treated sites were based on the recollections of the investigators. The estimates were unbiased but arbitrary, and the prediction may be better than can be generally expected of the technique.

Example 3. The Grant Watershed Worksheets III.1 and III.2 (Grant)

For the Gulf and Atlantic region, John Hewlett, University of Georgia, (personal communication) has supplied data for Example 3. The basin is an 80-acre treated watershed where silvicultural activities occur on the Georgia Piedmont, south of Athens, in the Grant Memorial Forest. The watershed is a pine-hardwood combination with an initial leaf area index of 7 and an average rooting depth of about 6 feet. It was clearcut, roller chopped twice, and then planted — reducing the leaf area index to 0.5. Again, a single silvicultural prescription and one silvicultural state were selected for the small uniform basin. The net change in evapotranspiration was estimated in the following manner [and transferred to worksheet III.1 (Grant)]:

(1) Assuming a baseline LAI of 7, the baseline evapotranspiration by season (from fig. III.12) is tabulated as:

Season (item 5)	Precipitation (item 10)	Baseline ET (item 11)
Summer	41.2 cm (16.2 in)	32.1 cm (12.6 in)
Fall	30.2 cm (11.9 in)	24.9 cm (9.8 in)
Winter	40.3 cm (15.9 in)	11.4 cm (4.5 in)
Spring	20.6 cm (8.1 in)	23.7 cm (9.3 in)
Total	132.3 cm (52.1 in)	92.1 cm (36.2 in)

WORKSHEET III.1

Water available for streamflow for the existing condition in rainfall dominated regions

(1) Watershed name Grant #1 (2) Hydrologic region 3 (3) Total prescription area (acres) 80 (4) Latitude ______

Season name/ dates (5)	Silvicultural prescription		Area		Precipi- tation (cm) (10)	Baseline ET (cm) (11)	Basal area (ft^2/ac) (1[illegible]	Leaf area index (13)	ET modifier coef. (14)	Rooting depth modifier coef. (15)	Weighted adjusted ET (cm) (16)	Weighted adjusted seasonal ET (cm) (17)	Water available for sea- sonal stream- flow (cm) (18)
	Compartment (6)	Silvicultural state (7)	Acres (8)	Per- cent (9)									
Fall 9/1 - 11/30	Unimpacted	Forested	80	1.000	30.2	24.9		7	1.0	1.0	24.9		
	Impacted												
	Total for season		80	1.000	30.2						24.9	24.9	5.3
Winter 12/1 - 2/28	Unimpacted	Forested	80	1.000	40.3	11.4		7	1.0	1.0	11.4		
	Impacted												
	Total for season		80	1.000	40.3						11.4	11.4	28.9
Spring 3/1 - 5/31	Unimpacted	Forested	80	1.000	20.6	23.7		7	1.0	1.0	23.7		
	Impacted												
	Total for season		80	1.000	20.6						23.7	23.7	-3.1
Summer 6/1 - 8/31	Unimpacted	Forested	80	1.000	41.2	32.1		7	1.0	1.0	32.1		
	Impacted												
	Total for season		80	1.000	41.2						32.1	32.1	9.1
(19) Annual ET (cm)												92.1	
(20) Water available for annual streamflow (cm)													40.2

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in text.
(3),(4)	Supplied by user.
(5)	Seasons for rainfall dominated regions are fall (September, October, November), winter (December, January, February), spring (March, April, May), and summer (June, July, August).
(6)	The unimpacted compartment includes areas not affected by the silvicultural prescription. The impacted compartment includes areas affected by the silvicultural prescription.
(7)	Areas of similar hydrologic response as identified and delineated by vegetation or silvicultural state.
(8)	Supplied by user.
(9)	Column (8) ÷ item (3).
(10)	Measured or estimated by the user.
(11)	From figures III.10 to III.12; or user supplied.
(12)	Supplied by user. Unnecessary if leaf area index is known.
(13)	From figures III.13 and III.14; or user supplied.
(14)	From figures III.15 to III.17.
(15)	From figures III.18 to III.20.
(16)	Calculated as (11) x (14) x (15) x (9); or user supplied.
(17)	Seasonal sum of column (16).
(18)	Column (10) - column (17).
(19)	Sum of column (17).
(20)	Sum of column (18).

WORKSHEET III.2

Water available for streamflow for the proposed condition in rainfall dominated regions

(1) Watershed name Grant #1 (2) Hydrologic region 3 (3) Total prescription area (acres) 80 (4) Latitude ______

Season name/ dates (5)	Silvicultural prescription		Area		Precipi-tation (cm) (10)	Baseline ET (cm) (11)	Basal area (ft²/ac) (12)	Leaf area index (13)	ET modifier coef. (14)	Rooting depth modifier coef. (15)	Weighted adjusted ET (cm) (16)	Weighted adjusted seasonal ET (cm) (17)	Water available for seasonal stream-flow (cm) (18)
	Compartment (6)	Silvicultural state (7)	Acres (8)	Per-cent (9)									
Fall 9/1 - 11/30	Unimpacted												
	Impacted	Clearcut	80	1.000	30.2	24.9		0.5	.47	1.0	11.7		
	Total for season		80	1.000	30.2						11.7	11.7	18.5
Winter 12/1 - 2/28	Unimpacted												
	Impacted	Clearcut	80	1.000	40.3	11.4		0.5	.41	1.0	4.7		
	Total for season		80	1.000	40.3						4.7	4.7	35.6
Spring 3/1 - 5/31	Unimpacted												
	Impacted	Clearcut	80	1.000	20.6	23.7		0.5	.34	1.0	8.0		
	Total for season		80	1.000	20.6						8.0	8.0	12.6
Summer 6/1 - 8/31	Unimpacted												
	Impacted	Clearcut	80	1.000	41.2	32.1		0.5	.47	1.0	15.1		
	Total for season		80	1.000	41.2						15.1	15.1	26.1
(19) Annual ET (cm)												39.5	
(20) Water available for annual streamflow (cm)													92.8

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in text.
(3),(4)	Supplied by user.
(5)	Seasons for rainfall dominated regions are fall (September, October, November), winter (December, January, February), spring (March, April, May), and summer (June, July, August).
(6)	The unimpacted compartment includes areas not affected by the silvicultural prescription. The impacted compartment includes areas affected by the silvicultural prescription.
(7)	Areas of similar hydrologic response as identified and delineated by vegetation or silvicultural state.
(8)	Supplied by user.
(9)	Column (8) ÷ item (3).
(10)	Measured or estimated by the user.
(11)	From figures III.10 to III.12; or user supplied.
(12)	Supplied by user. Unnecessary if leaf area index is known.
(13)	From figures III.13 and III.14; or user supplied.
(14)	From figures III.15 to III.17.
(15)	From figures III.18 to III.20.
(16)	Calculated as (11) x (14) x (15) x (9); or user supplied.
(17)	Seasonal sum of column (16).
(18)	Column (10) - column (17).
(19)	Sum of column (17).
(20)	Sum of column (18).

(2) For post-silvicultural activity conditions [see worksheet III.2 (Grant)], with a LAI = .5, the estimates are tabulated as:

Season (item 5)	Baseline ET (item 11) (fig III.12)	ET modifier (item 14) (fig III.17)	Root modifier (item 15) (fig III.20)	Post-silvicultural activity ET (col 1 x 2 x 3)
Summer	32.1 cm	.47	1.0	15.1 cm
Fall	24.9 cm	.47	1.0	11.7 cm
Winter	11.4 cm	.41	1.0	4.7 cm
Spring	23.7 cm	.34	1.0	8.0 cm
Total	92.1 cm			39.5 cm

For the pre-treatment condition, the annual evapotranspiration loss is estimated as 36.2 inches (92.1 cm) from an average precipitation of 52.1 inches (132.3 cm). The water potentially available for streamflow is 15.9 inches (40.4 cm).

The potential change in flow based on changes in evapotranspiration from 92.1 cm (existing condition) to 39.5 cm (proposed condition) is 52.6 cm (20.7 in). Hewlett estimated the observed change at 11 inches by the paired watershed method. The simulated water available for streamflow increased from 15.9 to 36.6 inches.

PROCEDURAL DESCRIPTION: DETERMINING POTENTIAL CHANGES IN STREAMFLOW (STREAMFLOW ESTIMATION) (RAIN DOMINATED REGIONS)

APPALACHIAN MOUNTAINS AND HIGHLANDS (REGION 2)
GULF AND ATLANTIC COASTAL PLAIN AND PIEDMONT (REGION 3)
PACIFIC COAST REGIONS (PROVINCES 5, 6, 7)

Distributing the potential changes in streamflow associated with various silvicultural activities is more complex and contains more sources of error than does estimating evapotranspiration and the magnitude of change. Streamflow predictions not only contain all the errors inherent in the evapotranspiration predictions, but also those errors inherent in maintaining a time-and-space-variable soil water budget and in routing both saturated and unsaturated flows to the channel system. None of these factors involving routing have been simulated in this effort. Therefore, all calculations dealing with flow predictions deal with estimating the water onsite that is potentially available for streamflow.

The purpose of this procedure is to distribute the expected change in flow, as estimated by the preceding ET procedure, over some reasonable estimate of the baseline or pre-treatment flow regime.

It has already been noted that the objective is to estimate the streamflow change and not the absolute value. Numerous simulations were made for each watershed data set to determine the effect of altering various watershed parameters and cover conditions on potential streamflow. The complexity of the data generated is significant because simulations were made on five to six cover conditions, three soil depths, two aspects, and several latitudes (watersheds) for each region. To facilitate presentation of the results, a least squares technique was used to fit the model wherein the change in flow (ΔQ) that occurs is a function of the antecedent flow level (pre-silvicultural activity flow, Q_i), the reduction in leaf area index (CD), the aspect (AS), the rooting or soil depth (RD).

The technique is not, however, a true regression, and estimates of error are impossible since the data base is simulated. The least squares model does represent the relationship that existed between the change in flow and the various levels of the other parameters used in the simulations.

PROCEDURAL FLOW CHART

A flow chart for the suggested methodology of calculating potential changes in streamflow associated with silvicultural practices is presented in figure III.21.

At the end of this section are three examples which have been developed to demonstrate application of the methodology; the worksheets for each example (III.3 and III.4) are summaries of calculations performed. A detailed description for each step follows.

HYDROLOGIC REGION OR PROVINCE

Decide which region or province most nearly approximates the hydrologic regime for the watershed of interest. Streamflow calculations are based upon regional hydrologic relationships, and the regional characterization is the same for this procedure as it was for the ET procedure.

ANNUAL HYDROGRAPH AVAILABLE?

To distribute the expected changes in flow, it must be known if a representative hydrograph is available for the site. If not, the methodology presented includes a flow duration curve represen-

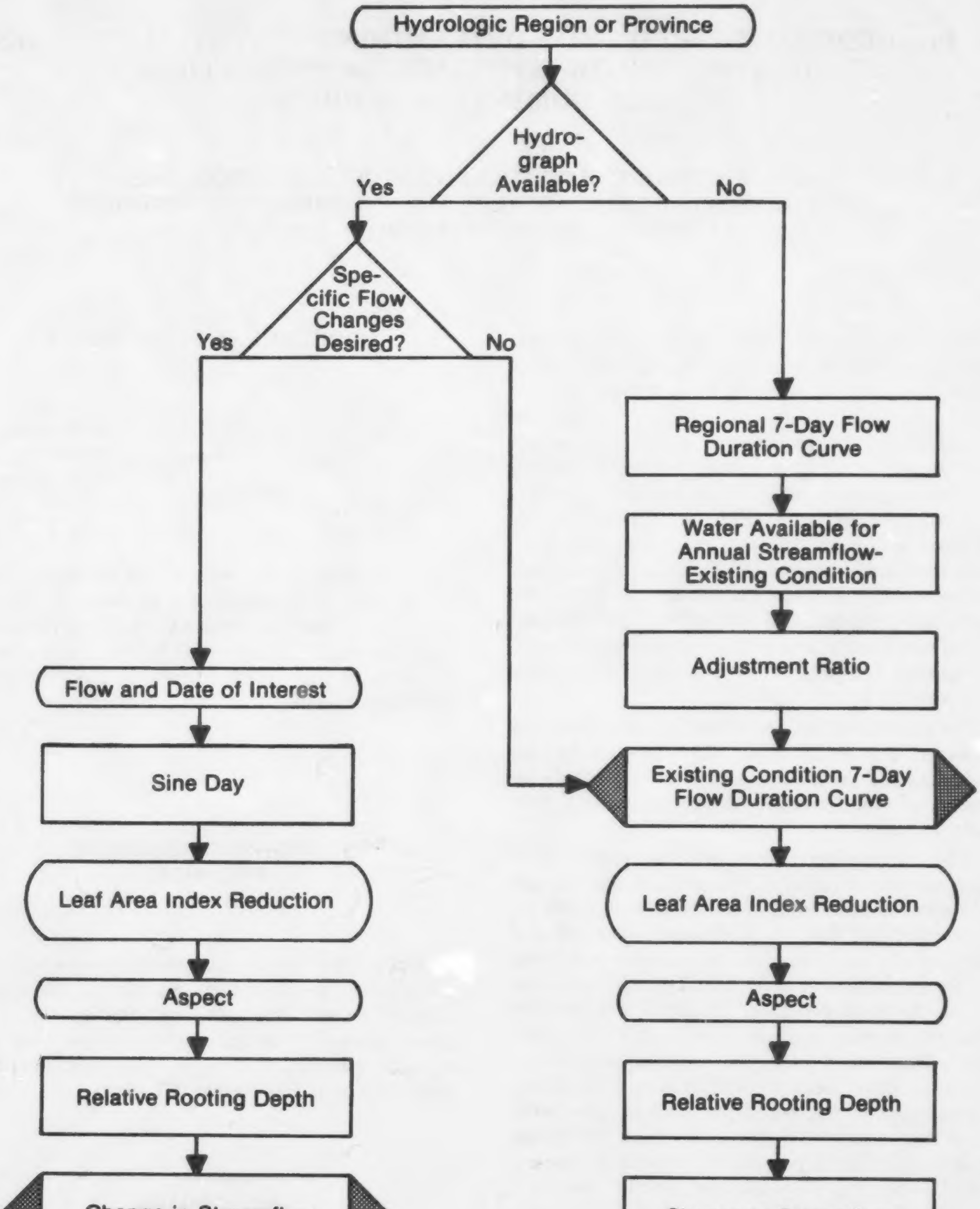

Hydrologic Region or Province
Hydrograph Available?
Yes
No
Specific Flow Changes Desired?
Yes
No
Regional 7-Day Flow Duration Curve
Water Available for Annual Streamflow-Existing Condition
Adjustment Ratio
Flow and Date of Interest
Sine Day
Existing Condition 7-Day Flow Duration Curve
Leaf Area Index Reduction
Leaf Area Index Reduction
Aspect
Aspect
Relative Rooting Depth
Relative Rooting Depth
Change in Streamflow
Change in Streamflow
Proposed Condition 7-Day Flow Duration Curve

Figure III.21.—Flow chart of methodology for determining 7-day flow duration curve and change in streamflow for specific flow change for rainfall dominated regions.

tative of each region over which changes in flow can be distributed. If a site specific hydrograph is not available, proceed to the block "Regional 7-Day Flow Duration Curves." If a representative hydrograph is available, proceed to the block "Specific Flow Changes Desired?"

SPECIFIC FLOW CHANGES DESIRED?

If a site specific hydrograph is available, there are two options. First, a determination of the expected change in flow for specific flow levels as a function of the day or time of year when the flow level might occur can be performed. This would apply when concerned with impacts on in-stream flow needs or on temperature. Changes in specific flow levels do not replace the procedure for distributing annual changes; it is another analytical tool. In most applications interest will be in distributing the change in annual flow over the entire hydrograph. (This constitutes a "no" answer.) In this case, proceed to the section on "Existing Condition 7-Day Flow Duration Curve" since a site specific flow duration curve can be constructed from the hydrograph. If estimates of changes in specific flow levels only are desired, proceed to the "Flow and Date of Interest" section.

REGIONAL 7-DAY FLOW DURATION CURVE

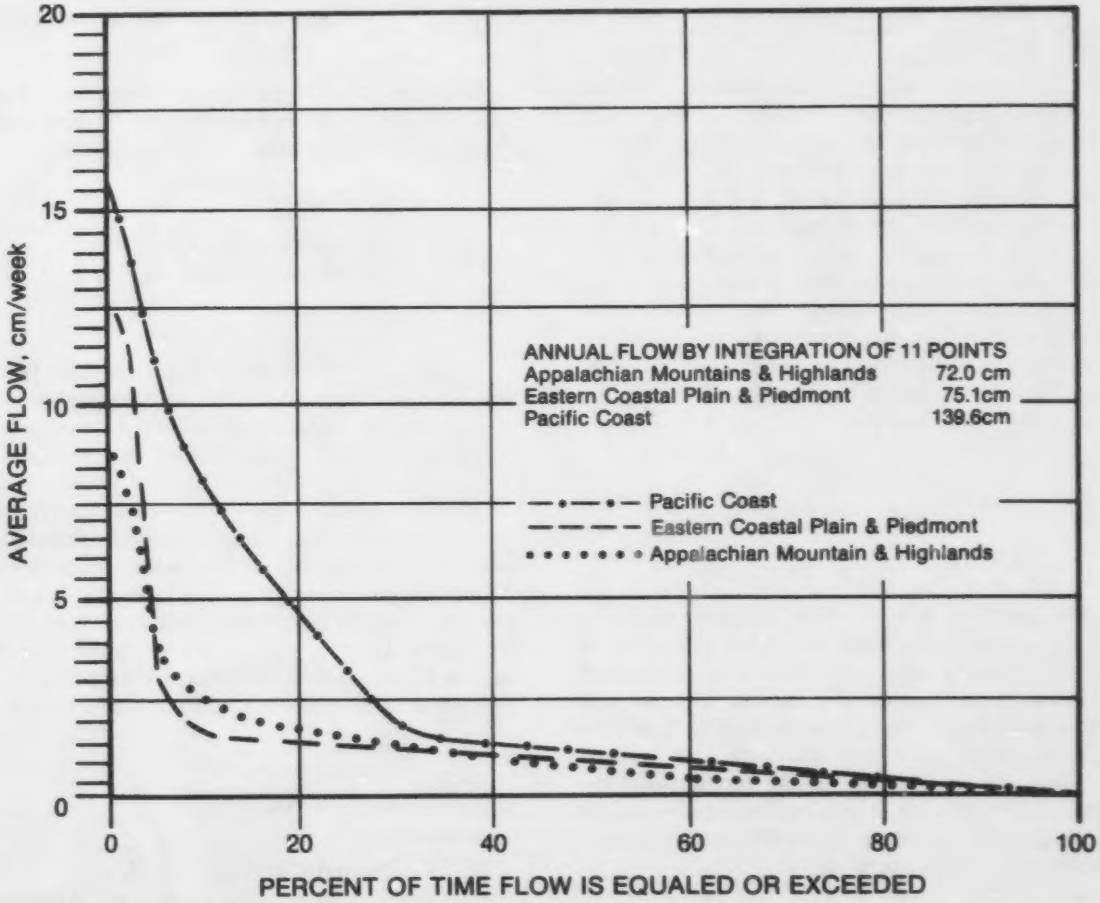


Figure III.22.—Potential excess water available for streamflow, 7-day flow duration curve for the Pacific Coast hydrologic provinces—Northwest (5), Continental/Maritime (6), and Central Sierra (7); for Appalachian Mountains and Highlands hydrologic region (2); and for the Eastern Coastal Plain and Piedmont hydrologic region (3).

Figure III.22 represents distributions of water potentially available for streamflow for each of the regions presented as 7-day flow duration curves. As such, they represent the average expected 7-day flow distribution for the conditions under which the simulations for each region were made. The major problem with presenting a normalized flow duration curve is that the normal variation in climatic, physiographic, and local basin characteristics forces almost every annual distribution of flow to be unique in both time and space. The assumption made at this point is that a site specific curve is not available. Therefore, select the duration curve for the region and adjust it for site specific conditions.

WATER AVAILABLE FOR ANNUAL STREAMFLOW—EXISTING CONDITION

The flow duration curves presented in figure III.22 represent average distributions for the watershed years simulated in each region. As such, they represent the distribution of a specific volume of water for each region and that volume may or may not represent the expected flow from the site; an adjustment is therefore necessary. The expected flow from the site for either baseline or existing condition has already been calculated in the procedure for determining evapotranspiration. Now the given flow duration curve (from fig. III.22) must be scaled to reflect the expected flow. This would not be necessary if a site specific flow duration curve were available.

ADJUSTMENT RATIO

The baseline potential flow duration curve for the hydrologic region must be adjusted for the site specific existing condition. This is done through multiplication of selected points on the curve by adjustment ratio. The adjustment ratio is defined as the ratio of water available for annual streamflow estimated by the ET procedure to the total water available for streamflow represented by the 7-day flow duration curve for the hydrologic region (fig. III.22) expressed as:

$$AR = \frac{Q_w}{Q_R} \qquad \text{(III.6)}$$

where:

AR = adjustment ratio

Q_w = water available for annual streamflow for the existing condition (from ET calculation, Eq. III.5)

Q_R = total water available for streamflow represented by the regional 7-day flow duration curve. (fig III.22)

For Coweeta, for example, the adjustment ratio is:

$$AR = \frac{104.9}{72.0} = 1.457$$

where:

104.9 cm = water available for annual streamflow for the existing condition

72.0 cm = total water available for streamflow represented by the regional 7-day flow duration curve (from fig. III.22).

Once the adjustment ratio is determined, a site specific flow duration curve for the existing condition can be constructed.

EXISTING CONDITION 7-DAY FLOW DURATION CURVE

If a site specific 7-day flow duration curve for the existing condition is available, no adjustment is necessary here. However, flow duration curves from figure III.22 need to be adjusted in the following manner. An acceptable number of points on the regional 7-day flow duration curve (fig. III.22) must be selected such that a new line can be fitted after adjusting the points for site specific conditions. (For example, 11 points at 10 percent intervals such as from 0 to 100 percent may be chosen.) The discharge (Q_{R_i}) for each point (i) chosen from the regional 7-day flow duration curve is multiplied by the adjustment ratio to give an adjusted flow level (Q_i). For example.

$$Q_i = Q_{R_i} \times AR \qquad \text{(III.7)}$$

where:

Q_i = adjusted flow level

Q_{R_i} = the discharge for each point (i) on the regional 7-day flow duration curve

AR = adjustment ratio

The existing condition 7-day flow duration curve is the plot of adjusted flow levels (Q_i) versus the corresponding percent of time the flow is equaled or exceeded.

See worksheets III.3 (Needle Branch, Coweeta, Grant) for detailed examples of determining the existing condition 7-day flow duration curve.

To this point, site specific estimates of the 7-day flow duration curve for baseline or existing conditions have been made. If a change in vegetal state is proposed, the following sections describe the procedures necessary to modify the existing flow duration curve to reflect the impact of the vegetation change.

In order to calculate the change in streamflow due to the change from existing to proposed conditions, it is necessary to estimate the leaf area index reduction, aspect, and relative rooting depth.

LEAF AREA INDEX REDUCTION

A representative value for the reduction of leaf area index (LAI) in units of LAI due to vegetation changes between existing and proposed conditions must be supplied. Reduction in LAI is symbolized as "CD." As indicated previously, basal area can be used to estimate leaf area index.

ASPECT

A representative aspect for the watershed or watershed subunit in coded form must be supplied. The aspect code is as follows: North aspect = −1, south aspect = +1, east or west aspect = 0.

RELATIVE ROOTING DEPTH

Relative rooting depth (RD) for the region is supplied. It is calculated as:

$$RD = \frac{RD_w}{RD_A} \qquad \text{(III.8)}$$

where:

RD = relative rooting depth for watershed

RD_w = rooting depth for watershed

RD_A = average rooting depth for region

The average regional rooting depth has been discussed in a previous section.

CHANGE IN STREAMFLOW

As noted earlier, the expected change in annual flow is a reflection of changes in evapotranspiration resulting from the average change in leaf area index for the watershed. This section deals with the distribution of that change in flow over the annual distribution or the flow duration curve. This is done using least square techniques.

$$\Delta Q_i = b_0 + b_1 Q_i + b_2 CD + b_3 AS + b_4 RD \qquad \text{(III.9)}$$

where:

ΔQ_i = simulated potential change in water available for streamflow

Q_i = simulated potential water available for streamflow under baseline or undisturbed conditions (cm/week)

CD = the reduction in leaf area index (in units of LAI) from baseline

AS = dummy variable for aspect (−1 for north slopes, +1 for south slopes, 0 for east or west slopes)

RD = relative rooting depth

b_i = least squares coefficient

The coefficients (tables III.3, III.4, and III.5) for the regional least square models are as follow:

Table III.3.—Least square coefficients for equation III.9 for simulated potential change in water available for streamflow for the Pacific Coast provinces

Variable	Coefficient	Estimated coefficients
Intercept	b_0	-0.05
Q_i	b_1	-0.05
CD	b_2	0.025
AS	b_3	0.013
RD	b_4	0.005

Table III.4.—Least square coefficients for equation III.9 for simulated potential change in water available for streamflow for the Appalachian Mountains and Highlands

Variable	Coefficient	Estimated coefficients
Intercept	b_0	-0.03
Q_i	b_1	-0.03
CD	b_2	0.13
AS	b_3	0.02
RD	b_4	0.03

Table III.5.—Least square coefficients for equation III.9 for simulated potential change in water avilable for streamflow for the Coastal Plain/Piedmont

Variable	Coefficient	Estimated coefficients
Intercept	b_0	-.19
Q_i	b_1	-.12
CD	b_2	.20
AS	b_3	.01
RD	b_4	.02

Addition of the potential change for streamflow for interval i (ΔQ_i) to the existing streamflow for interval i (Q_i) will yield the post-treatment potential streamflow for interval i ($Q_i + \Delta Q_i$).

The average 7-day potential flow for the existing condition can be estimated from the flow duration curve using the equation:

$$Q_{average} = \left[.5(Q_1 + Q_N) + \sum_{i=2}^{N-1} Q_i\right] \times \frac{1.00}{N-1} \quad \text{(III.10)}$$

or for N = 11 points:

$$Q_{average} = \left[.5(Q_1 + Q_{11}) + \sum_{i=2}^{10} Q_i\right] \times .10$$

The same applies to the post-treatment condition flows ($Q_i + \Delta Q_i$).

Examples of calculations have been worked out and presented in worksheets III.3 and III.4. The output from the calculations is an estimate of water available for streamflow distributed over time.

The least squares method is one of two methods for estimating increase in streamflow due to silvicultural activity. The other method involves computing the difference in water available for streamflow between existing and proposed conditions using evapotranspiration calculations; i.e., subtraction of item (20), worksheet III.1 from item (20), worksheet III.2 will accomplish this.

An estimate of the change in flow using the least squares method can be made as follows. The average 7-day flow for either pre- or post-treatment condition can be estimated from the respective flow duration curves using equation III.9 or III.10. The average 7-day flow, when multiplied by 52, yields the average annual flow. The same applies to the post-treatment condition flows ($Q_i + \Delta Q_i$). The difference in the two is also an estimate of the expected change in flow resulting from the proposed activity; it will compare with, but not be the same as, the estimates using the evapotranspiration calculations.

PROPOSED CONDITION 7-DAY FLOW DURATION CURVE

The proposed condition 7-day flow duration curve is a plot of each adjusted flow level ($Q_i + \Delta Q_i$) versus percent of time that flow ($Q_i + \Delta Q_i$) is equaled or exceeded.

The primary purpose of this methodology is to provide 7-day flow duration curves for conditions before and after a proposed silvicultural activity. At this point, sufficient instruction has been given to enable construction of existing and proposed flow duration curves. The next step, after plotting the flow duration curves, would be to proceed to the subsequent procedural chapters. However, if changes in streamflow for a specific date or for a specific flow level are required, the descriptions that follow outline the procedure for their estimation.

If an evaluation of the effect of time of year on changes in various flow levels is not needed, the analysis is now complete. If estimates of time dependent changes are necessary, the analysis continues.

It should be noted that the procedure distributes the impact of average vegetal changes over the average watershed flow duration curve. The ET estimations made previously were not lumped but were actually calculated by treatment and prescription; they were then area weighted to obtain the net annual change. This is not true of the flow distribution procedure because it tends to lump the various treatments and prescriptions into a single watershed average, as the methodology is strongest when applied in this manner. However, the method is flexible; if separate evaluations of each treatment or prescription are desired, they can be determined and the relative effect of each component can be evaluated in the same manner.

This depends on the objectives defined and the resolution desired.

FLOW AND DATE OF INTEREST

If an annual hydrograph for the existing condition is available and/or if changes in flow for specific flow levels as functions of date of occurrence are desired, time dependent adjustments can be made to reflect the effect of silvicultural activity using the following least squares model:

$$\Delta Q_i = b_o + b_1 Q_i + b_2 CD + CD + b_3 AS + b_4 RD + b_5 \text{Sine Day} \qquad (\text{III.11})$$

With the exception of sine day, all variables are as defined in equation III.9.

SINE DAY

In addition to fitting equation III.9 for use in adjusting the potential flow duration curve, an additional parameter was fitted for adjusting the annual hydrograph. Hewlett and others (1977), Hewlett and Hibbert (1967) and others have found that the sine of the day (sine of the numerical day in the year starting with December 21 as day 1, January 1 as day 11 and so on) is useful in expressing the annual cycle of hydrologic processes.

$$\text{Sine Day} = \sin\left[\frac{360 \times \text{Day \#}}{365}\right] + 2 \qquad (\text{III.12})$$

Values of sine day for selected days may be found in table III.6.

LEAF AREA INDEX REDUCTION

An estimate of the reduction in leaf area index is required as defined for equation III.9.

ASPECT

An estimate of aspect is required as defined in equation III.9.

RELATIVE ROOTING DEPTH

An estimate of relative rooting depth is required as defined in equation III.9.

CHANGE IN STREAMFLOW

Equation III.11 is used to estimate the change in streamflow caused by silvicultural activity for specific levels or dates.

The estimated coefficients for equation III.11 by regions may be found in tables III.7, III.8, or III.9.

Addition of the change in streamflow for a hydrograph flow or date i (ΔQ_i) to the hydrograph streamflow value for flow or date i (Q_i) gives hydrograph streamflow value ($Q_i + \Delta Q_i$) for the proposed condition at flow or date i.

Table III.6.—Sine of day value (S) for use with flow prediction equation III.11. Where S = sin (360 × day #/365) + 2

Day	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1	1.66	2.17	2.65	2.94	2.99	2.77	2.38	1.84	1.37	1.06	1.01	1.23
7	1.76	2.27	2.72	2.98	2.97	2.70	2.26	1.74	1.29	1.03	1.04	1.30
14	1.88	2.39	2.80	2.99	2.93	2.61	2.15	1.62	1.21	1.01	1.08	1.39
21	2.00	2.49	2.87	3.00	2.88	2.52	2.03	1.51	1.14	1.00	1.13	1.49
28	2.12	2.59	2.92	2.99	2.82	2.41	1.90	1.43	1.09	1.01	1.20	1.60

Table III.7.—Least square coefficients for equation III.11 for the Pacific Coast provinces-low elevation

Parameter	Coefficient symbol	Estimated coefficient value
Intercept	b_0	0.21
Q_i	b_1	-0.16
CD	b_2	0.02
AS	b_3	0.001
RD	b_4	0.05
Sine day	b_5	0.91

Table III.8.—Least square coefficients for equation III.11 for the Appalachian Mountains and Highlands

Parameter	Coefficient symbol	Estimated coefficient value
Intercept	b_0	-0.06
Q_i	b_1	0.01
CD	b_2	0.13
AS	b_3	0.04
RD	b_4	0.02
Sine day	b_5	1.17

Table III.9.—Least square coefficients for equation III.11 for the Coastal Plain/Piedmont

Parameter	Coefficient symbol	Estimated coefficient value
Intercept	b_0	-0.19
Q_i	b_1	0.13
CD	b_2	0.20
AS	b_3	0.01
RD	b_4	0.02
Sine day	b_5	-0.18

The equation (III.11) allows the adjustment of specific flow levels (Q_i) as a function of the time of occurrence. For example, the effect of treatment on a 2 cm flow level in March would not necessarily be the same as the effect of treatment on the same flow level if it were to occur in August.

Examples: Determining Potential Changes In Streamflow

An illustration of the calculations has been worked out and is presented in worksheets III.3 and III.4. The example uses the regional potential flow duration curve and adjusts it for annual streamflow estimated in the evapotranspiration calculation for Needle Branch watershed previously presented (fig III.22a).

Output from the calculations (wkshts. III.3 and III.4) is an estimate of water available for annual streamflow distributed over time. Both existing and proposed condition levels are expressed as 7-day average flow in cubic feet per second. These values are then entered on the worksheets for sediment analysis presented in chapter VI.

Similar examples have been completed on worksheets III.3 and III.4 for Coweeta (plotted on fig. III.22b) representing the Appalachian Mountains and Highlands and for Grant Memorial Forest (fig. III.22c) representing the Coastal Plain/Piedmont.

The following summary compares the evapotranspiration method and the least squares method to observed values for the three watersheds used in the evapotranspiration estimation procedure.

Table III.10.—A comparison (cm) of the evapotranspiration method and the least squares method to measured values for the three watershed examples

Watershed	ET method	Streamflow increases—Least squares method	Observed
Needle Branch	58.0	41.5	50.3[1]
Coweeta	15.9	15.0	15.8[2]
Grant WS#1	52.6	54.5	28.0[3]

[1] Harr, D., personal communication.
[2] Hewlett and Douglass (1968).
[3] Hewlett, J., University of Georgia, personal communication.

WORKSHEET III.3

Flow duration curve for existing condition rain dominated regions

(1) Watershed name Needle Branch (2) Hydrologic region 5

(3) Water available for annual streamflow existing condition (cm) 134.3

(4) Annual flow from duration curve for hydrologic region (cm) 139.6

(5) Adjustment ratio (3)/(4) .962

Point number i (6)	Percent of time flow is equaled or exceeded (7)	Regional flow (cm/7 days) (8)	Existing potential flow Q_i (cm/7 days) (9)	Existing potential flow Q_i (cfs) (10)
1	0	15.5	14.9	8.3
2	10	8.0	7.7	4.3
3	20	5.0	4.8	2.7
4	30	2.0	1.9	1.1
5	40	1.3	1.3	.7
6	50	1.15	1.1	.6
7	60	.75	.7	.4
8	70	.50	.5	.3
9	80	.25	.2	.1
10	90	.15	.1	.06
11	100	0	0	0

Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in text.
(3)	Item (20) of worksheet III.1.
(4)	From figure III.22.
(5)	Item (3) ÷ item (4).
(6)	Number of each point taken from figure III.22; or user supplied.
(7)	X-axis of figure III.22.
(8)	From figure III.22; or user supplied (unnecessary if col. (9) is user supplied).
(9)	Column (8) x item (5); or user supplied.
(10)	Column (9) x area (acres) x 0.002363.

WORKSHEET III.4

Flow duration curve for proposed condition
rain dominated regions--annual hydrograph unavailable

(1) Watershed name Needle Branch (2) Hydrologic region 2 (3) Watershed aspect code (AS) 1

(4) Existing condition LAI 40 (5) Proposed condition LAI 1 (6) Change in LAI (CD) 39

(7) Rooting depth modifier coefficient (RD) 1 (8) b_0 -.05 (9) b_1 -.05 (10) b_2 .025 (11) b_3 -.013 (12) b_4 .006

Point number i (13)	Percent of time flow is equaled or exceeded (14)	Existing potential flow Q_i (15)	b_0 (16)	b_1Q_i (17)	b_2CD (18)	b_3AS (19)	b_4RD (20)	Q_i (cm) (21)	$Q_i + \Delta Q_i$ (cm) (22)	$Q_i + \Delta Q_i$ (cfs) (23)
1	0	14.9	-.05	-.75	.975	-.013	.006	.18	15.1	8.5
2	10	7.7	-.05	-.39	.975	-.013	.006	.54	8.2	4.6
3	20	4.8	-.05	-.24	.975	-.013	.006	.69	5.5	3.1
4	30	1.9	-.05	-.10	.975	-.013	.006	.83	2.7	1.5
5	40	1.3	-.05	-.07	.975	-.013	.006	.86	2.2	1.2
6	50	1.1	-.05	-.06	.975	-.013	.006	.87	2.0	1.1
7	60	.7	-.05	-.04	.975	-.013	.006	.89	1.6	.9
8	70	.5	-.05	-.03	.975	-.013	.006	.90	1.4	.8
9	80	.2	-.05	-.01	.975	-.013	.006	.92	1.1	.6
10	90	.1	-.05	-.01	.975	-.013	.006	.92	1.0	.6
11	100	0	-.05	0	.975	-.013	.006	.93	.9	.5

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces given in the text.
(3)	Northern aspect = +1, southern aspect = -1, eastern or western aspect = 0.
(4)	Area weighted average for existing condition.
(5)	Area weighted average for proposed condition.
(6)	Item (4) - item (5).
(7)	Area weighted average.
(8)-(12)	From tables III.3 to III.5.

Item or Col. No.	Notes
(13)	Column (6) of worksheet III.3.
(14)	Column (7) of worksheet III.3.
(15)	Column (9) of worksheet III.3.
(16)	Item (8).
(17)	Item (9) x column (15).
(18)	Item (10) x item (6).
(19)	Item (11) x item (3).
(20)	Item (12) x item (7).
(21)	Columns (16) + (17) + (18) + (19) + (20).
(22)	Column (15) + column (21).
(23)	Column (22) x area (ac) x 0.002363 for 7-day intervals.

WORKSHEET III.3

Flow duration curve for existing condition rain dominated regions

(1) Watershed name Coweeta (2) Hydrologic region 2

(3) Water available for annual streamflow existing condition (cm) 104.9

(4) Annual flow from duration curve for hydrologic region (cm) 72.0

(5) Adjustment ratio (3)/(4) 1.457

Point number I (6)	Percent of time flow is equaled or exceeded (7)	Regional flow (cm/7 days) (8)	Existing potential flow Q_I (cm/7 days) (9)	Existing potential flow Q_I (cfs) (10)
1	0	9.0	13.1	11.0
2	10	2.7	3.9	3.3
3	20	1.9	2.8	2.4
4	30	1.4	2.0	1.7
5	40	1.2	1.8	1.5
6	50	.7	1.0	.8
7	60	.5	.7	.6
8	70	.4	.6	.5
9	80	.3	.4	.3
10	90	.2	.3	.25
11	100	0	0	0

Col. No. Notes

(1) Identification of watershed or watershed subunit.
(2) Descriptions of hydrologic regions and provinces are given in text.
(3) Item (20) of worksheet III.1.
(4) From figure III.22.
(5) Item (3) ÷ item (4).
(6) Number of each point taken from figure III.22; or user supplied.
(7) X-axis of figure III.22.
(8) From figure III.22; or user supplied (unnecessary if col. (9) is user supplied).
(9) Column (8) x item (5); or user supplied.
(10) Column (9) x area (acres) x 0.002363.

WORKSHEET III.4

Flow duration curve for proposed condition
rain dominated regions--annual hydrograph unavailable

(1) Watershed name Coweeta (2) Hydrologic region 2 (3) Watershed aspect code (AS) 0

(4) Existing condition LAI 6.0 (5) Proposed condition LAI 3.2 (6) Change in LAI (CD) 2.8

(7) Rooting depth modifier coefficient (RD) 1 (8) b_0 -.03 (9) b_1 -.03 (10) b_2 .13 (11) b_3 .02 (12) b_4 .03

Point number i (13)	Percent of time flow is equaled or exceeded (14)	Existing potential flow Q_i (15)	b_0 (16)	b_1Q_i (17)	b_2CD (18)	b_3AS (19)	b_4RD (20)	Q_i (cm) (21)	$Q_i + \Delta Q_i$ (cm) (22)	$Q_i + \Delta Q_i$ (cfs) (23)
1	0	13.1	-.03	-.39	.36	0	.03	-.03	12.9	10.9
2	10	3.9	-.03	-.12	.36	0	.03	.24	4.1	3.4
3	20	2.8	-.03	-.08	.36	0	.03	.28	3.1	2.6
4	30	2.0	-.03	-.06	.36	0	.03	.30	2.3	1.9
5	40	1.8	-.03	-.05	.36	0	.03	.31	2.1	1.8
6	50	1.0	-.03	-.03	.36	0	.03	.33	1.3	1.1
7	60	.7	-.03	-.02	.36	0	.03	.34	1.0	.8
8	70	.6	-.03	-.02	.36	0	.03	.34	.9	.8
9	80	.4	-.03	-.01	.36	0	.03	.35	.8	.7
10	90	.3	-.03	-.01	.36	0	.03	.35	.7	.6
11	100	0	-.03	0	.36	0	.03	.36	.4	.3

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces given in the text.
(3)	Northern aspect = +1, southern aspect = -1, eastern or western aspect = 0.
(4)	Area weighted average for existing condition.
(5)	Area weighted average for proposed condition.
(6)	Item (4) - item (5).
(7)	Area weighted average.
(8)-(12)	From tables III.3 to III.5.

Item or Col. No.	Notes
(13)	Column (6) of worksheet III.3.
(14)	Column (7) of worksheet III.3.
(15)	Column (9) of worksheet III.3.
(16)	Item (8).
(17)	Item (9) x column (15).
(18)	Item (10) x item (6).
(19)	Item (11) x item (3).
(20)	Item (12) x item (7).
(21)	Columns (16) + (17) + (18) + (19) + (20).
(22)	Column (15) + column (21).
(23)	Column (22) x area (ac) x 0.002363 for 7-day intervals.

WORKSHEET III.3

Flow duration curve for existing condition rain dominated regions

(1) Watershed name Grant #1 (2) Hydrologic region 3

(3) Water available for annual streamflow existing condition (cm) 40.2

(4) Annual flow from duration curve for hydrologic region (cm) 75.1

(5) Adjustment ratio (3)/(4) .535

Point number i (6)	Percent of time flow is equaled or exceeded (7)	Regional flow (cm/7 days) (8)	Existing potential flow Q_i (cm/7 days) (9)	Existing potential flow Q_i (cfs) (10)
1	0	12.5	6.7	1.3
2	10	1.8	1.0	.2
3	20	1.3	.7	.13
4	30	1.2	.6	.11
5	40	1.0	.5	.09
6	50	.9	.5	.09
7	60	.8	.4	.08
8	70	.6	.3	.06
9	80	.4	.2	.04
10	90	.2	.1	.02
11	100	0	0	0

Notes

Col. No.	
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in text.
(3)	Item (20) of worksheet III.1.
(4)	From figure III.22.
(5)	Item (3) ÷ item (4).
(6)	Number of each point taken from figure III.22; or user supplied.
(7)	X-axis of figure III.22.
(8)	From figure III.22; or user supplied (unnecessary if col. (9) is user supplied).
(9)	Column (8) x item (5); or user supplied.
(10)	Column (9) x area (acres) x 0.002363.

WORKSHEET III.4

Flow duration curve for proposed condition
rain dominated regions--annual hydrograph unavailable

(1) Watershed name Grant #1 (2) Hydrologic region 3 (3) Watershed aspect code (AS) 0

(4) Existing condition LAI 7.0 (5) Proposed condition LAI .5 (6) Change in LAI (CD) 6.5

(7) Rooting depth modifier coefficient (RD) 1 (8) b_0 -.19 (9) b_1 -.12 (10) b_2 .20 (11) b_3 .01 (12) b_4 .02

Point number i (13)	Percent of time flow is equaled or exceeded (14)	Existing potential flow Q_i (15)	b_0 (16)	b_1Q_i (17)	b_2CD (18)	b_3AS (19)	b_4RD (20)	ΔQ_i (cm) (21)	$Q_i + \Delta Q_i$ (cm) (22)	$Q_i + \Delta Q_i$ (cfs) (23)
1	0	6.7	-.19	-.80	1.3	0	.02	.33	7.0	1.3
2	10	1.0	-.19	-.12	1.3	0	.02	1.01	2.0	.4
3	20	.7	-.19	-.08	1.3	0	.02	1.05	1.8	.34
4	30	.6	-.19	-.07	1.3	0	.02	1.06	1.7	.32
5	40	.5	-.19	-.06	1.3	0	.02	1.07	1.6	.30
6	50	.5	-.19	-.06	1.3	0	.02	1.07	1.6	.30
7	60	.4	-.19	-.05	1.3	0	.02	1.08	1.5	.28
8	70	.3	-.19	-.04	1.3	0	.02	1.09	1.4	.26
9	80	.2	-.19	-.02	1.3	0	.02	1.11	1.3	.25
10	90	.1	-.19	-.01	1.3	0	.02	1.12	1.2	.23
11	100	0	-.19	0	1.3	0	.02	1.13	1.1	.21

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces given in the text.
(3)	Northern aspect = +1, southern aspect = -1, eastern or western aspect = 0.
(4)	Area weighted average for existing condition.
(5)	Area weighted average for proposed condition.
(6)	Item (4) - Item (5).
(7)	Area weighted average.
(8)-(12)	From tables III.3 to III.5.

Item or Col. No.	Notes
(13)	Column (6) of worksheet III.3.
(14)	Column (7) of worksheet III.3.
(15)	Column (9) of worksheet III.3.
(16)	Item (8).
(17)	Item (9) x column (15).
(18)	Item (10) x Item (6).
(19)	Item (11) x Item (3).
(20)	Item (12) x Item (7).
(21)	Columns (16) + (17) + (18) + (19) + (20).
(22)	Column (15) + column (21).
(23)	Column (22) x area (ac) x 0.002363 for 7-day intervals.

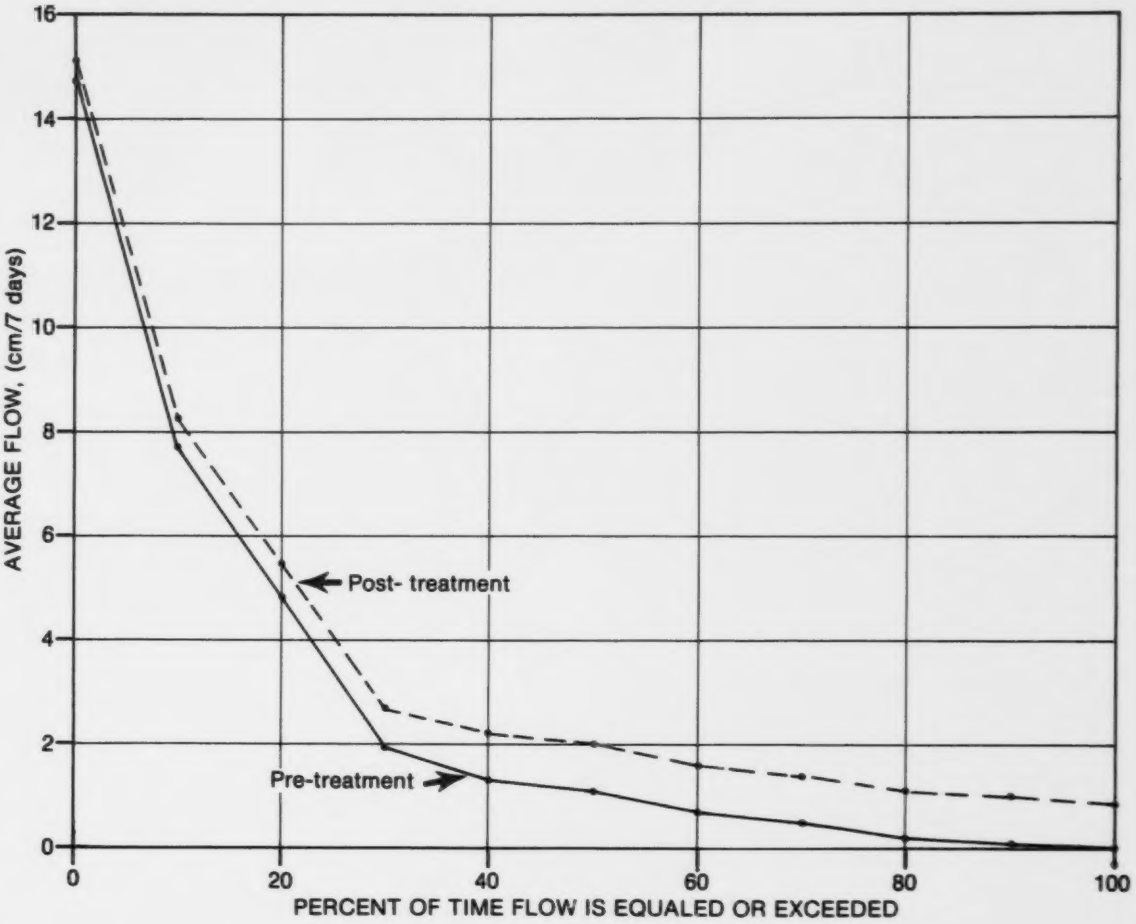


Figure III.22a.—Pre- and post-silvicultural activity 7-day flow duration curve for Needle Branch.

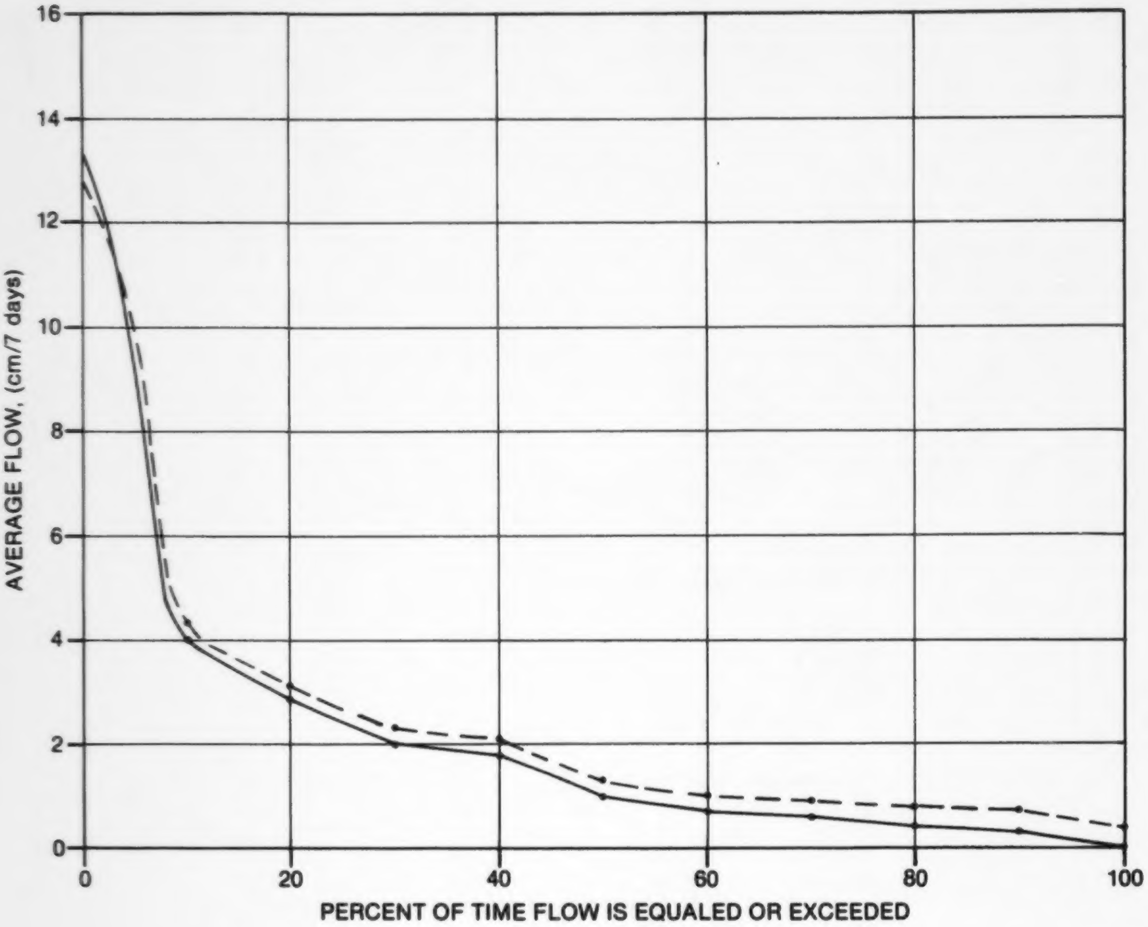


Figure III.22b.—Pre- and post-silvicultural activity 7-day flow duration curve for Coweeta.

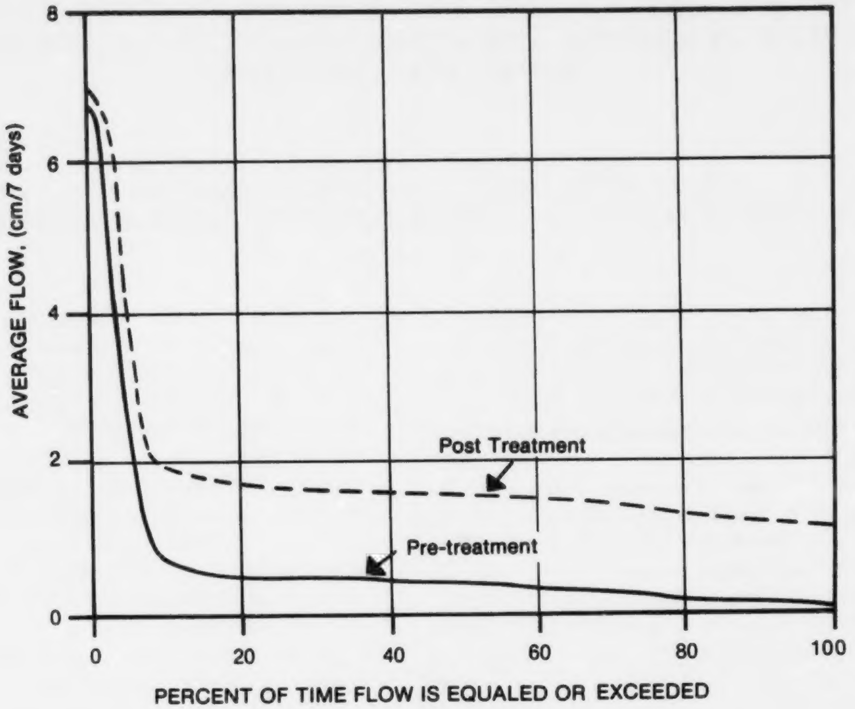


Figure III.22c.—Pre- and post-silvicultural activity 7-day flow duration curve for Grant Memorial Forest Watershed.

PROCEDURAL DESCRIPTION: DETERMINING EVAPOTRANSPIRATION AND WATER AVAILABLE FOR STREAMFLOW (ET ESTIMATION) (SNOW DOMINATED REGIONS)

NEW ENGLAND/LAKE STATES (REGION 1)
ROCKY MOUNTAIN/INLAND INTERMOUNTAIN (REGION 4)
PACIFIC COAST REGION, HIGHER ELEVATION ZONES (PROVINCES 5, 6, 7)

The following methodology is presented as a means of estimating evapotranspiration and potential streamflow for existing and proposed conditions in snow dominated hydrologic regions.

In this handbook, the areas in which snow has a significant hydrologic role are the New England/Lake States hydrologic region (1), the Rocky Mountain/Inland Intermountain hydrologic region (4), and the higher elevation zones of the Pacific Coast hydrologic provinces (5, 6, and 7). These areas are shown in figure III.9a. It is unfortunate that for purposes of delineation the higher and lower elevations of the Pacific Coast provinces are separated, since hydrologically they are so closely interlocked. In fact, the greatest area of flood production in this province lies in the elevational band where snowpacks can be melted out by rainfall. Setting of the lower boundary of the high elevation zone at 4,000 feet reduces this problem somewhat.

Due to limited data from the snow dominated regions and the necessity to conserve space, there has been a great amount of "lumping" of regions and regional response. However, differentiations are made whenever possible.

REGIONAL DESCRIPTIONS

New England/Lake State Hydrologic Region (1)

This area actually comprises two separate provinces: New England and Lake States. Wide differences in wind and temperature subdivide the region into two sections.

Snow in the northeastern section of the province occurs in shallow packs, seldom over 3 feet in depth on the level; it may reach much greater depths at higher elevations. Subject to frequent incursions of Arctic air from Canada and warm storms from the Gulf Stream of the Atlantic Ocean, these snowpacks frequently develop very heavy ice layers on the surface. Spring rains on such packs yield a swift return flow to streams, causing rapid rises in the shallow rivers of the region. Continued rain melts the relatively thin packs, adding to the flood. Extremely cold winters and cool summers limit transpiration opportunities. Soils are frequently rocky and water-holding capacities vary extensively. In locations of glacial till where extensive ice cover does not exist, the melting snows are absorbed into the soil mantle.

In the Great Lakes portion of the region, ice layering becomes less of a phenomenon, but early spring melt and flooding become increasingly important. Snowpacks and snow become increasingly wetter as one approaches the upper portion of the Lower Peninsula and the Upper Peninsula of Michigan. Snowfall and snowpacks are deeper and drier than in much of New England. High water absorptive capacity of the soils, lack of extensive surface relief, and widespread bog (swamp) development prevent extensive flood threats from melting snow. High water tables generally provide sufficient water to meet potential evapotranspiration needs. While temperatures can become very frigid from incursions of Arctic air, the lakes provide an ameliorating influence.

Westward in Minnesota and Wisconsin, more frigid temperatures are the rule. Snows frequently are driven by high winds, and the dry snow is subject to much more redistribution than in other areas. Snow distribution is of little importance in the region except for this western edge.

Rocky Mountain/Inland Intermountain Hydrologic Region (4)

This vast area covers parts or all of South Dakota, Wyoming, Montana, Colorado, New Mexico, Arizona, Utah, and Idaho. Most of the water for the region comes from snowpacks which accumulate in winter and melt in summer. In general, winter temperatures are very cold, snows are dry, and snowpacks have a thermal gradient. That is, snow temperatures at the soil surface approach those of the soil itself (32°F or 0°C). Temperatures from the soil to the snowpack surface decrease, until at the air-snow interface they reach air temperature, frequently −40°. However, this region is far from homogenous and the climatic differences affecting snowpack performance should be recognized.

The entire region is subject to summer thunderstorms which can cause disastrous flooding and assist in recharging the soil water supply. The entire area is usually subject to snow deposition as a result of high winds and dry snow, except for two major transition zones — (1) northern New Mexico, southwestern Colorado, northern Arizona, and (2) northern Idaho. These are transition zones between the dry, low temperature snowpacks and continental frigid winter climate of the true Rocky Mountain chain, and the warm climate, wet snowpacks of the Pacific Coast. Dependent upon the direction from which the storms and air masses come, the snowpacks in these transition areas will be representative of one of the other major provinces all year; or they may resemble one province during part of the year and resemble the other during another part of the year.

In western Montana and in Wyoming plains and rolling hills, there is enormous displacement and redeposition of snow. This affects evapotranspiration and tree growth since it removes the scanty snow cover from vast areas and concentrates it in a few locations. Obviously, this favors increased plant growth and water use in these sites. Evaporation (sublimation) loss from blowing snow is extensive.

Snows in the Rocky Mountains of Wyoming and Colorado and in the Wasatch Mountains are dry and cold (the skiers' famed "powder snow"). Wind redeposition is extensive in large, open areas. Particularly in Colorado, much of the mountain chain lies in the Alpine Zone. Snowpacks mature and melt in response to "ground heat" from below and to warm air temperatures and increased solar radiation in the spring. The thermal gradient in such packs creates unstable snow layers; frequent avalanching occurs from this cause and from melting snow sliding over wind slab formations. Since most melt occurs from the surface of the pack downward, the pack largely wets up from the surface. Most melt water goes directly into the soil. Since the packs are "cold," first melt goes to satisfying the thermal demand needed to bring the snowpack to a thermal equilibrium (32°F or 0°C) throughout the pack.

The shallow snows in northern Arizona frequently are redeposited by wind. Because of the lower latitude and higher insolation in winter, however, midwinter melt is often sufficient to wet the surface and prevent further movement.

Southwestern Colorado, northern Idaho, and the Rocky Mountains of western Montana receive wetter snows and even occasional rain. These cause some limited ice layering in the snow in southwestern Colorado.

Pacific Coast Hydrologic Provinces (5, 6, and 7)

This region begins in the San Bernardino Mountains of southern California, continues northward through the Sierra Nevada of California, the Cascades of Washington and Oregon, and includes the mountain ridges and peaks of western and central Nevada. The same type of snowpacks occur northward through British Columbia and into southeastern Alaska, at least to Anchorage.

The maritime climate in the winter is warm and wet. Summers vary depending upon the particular portion of the province, but generally they are dry with little or no summer precipitation. Summer thunderstorm activity is extensive over the southern Sierra Nevada, adding some water to that area, largely in the relatively treeless alpine area. The remainder of the Pacific Coast province, with the exception of parts of Washington, receives little summer precipitation.

Fall and winter precipitation is normally snow, but extensive rainstorms sometimes occur up to 8,000 feet elevation in the Central Sierra (7). Significant snow falls at elevations down to 4,000 feet, and, on rare occasions, significant amounts fall to 2,000 feet. Rains remove snowpacks up to 6,000 feet elevation and infrequently remove significant parts of the packs to over 7,000 feet.

Snowpack depth is extremely variable and has been measured at maximum pack from 36 inches to over 275 inches.

Snow redistribution normally does not occur due to the wetness of the snow.

Snow metamorphism continues all winter as a result of the warm climate, and frequent ice lenses occur throughout the packs, particularly on south, open slopes. Temperatures normally remain at 32° F throughout the packs. When rain falls on packs significantly lower than 32°F, serious flooding can occur from rain and melt water flowing over the frozen layer (Smith 1974).

Snowpack configuration of these warm, wet snows typically consists of a mixture of heavy and light density layers having different maturation schedules and water-holding capacities. The configurations vary dramatically by aspect and by forest cover (Smith 1974, 1975).

Because of warm climate, frequent rains, and melting snow, snowpacks in the subalpine are usually wet and remain at thermal equilibrium throughout the snow season. Frequent snowfalls keep the albedo high (80-90) until spring melt out is well under way, at which time albedo drops to about 45 percent. Major winter melt is caused more from absorption of solar radiation by the rocks, trees and shrubs standing above the snow than from direct solar radiation to the pack. These, in turn, heat up and radiate sensible heat to the pack. This creates the major melt until late season low albedos of the snow increase radiation absorption by the pack.

Because of the isothermal, wet condition of the snow, forest cover change can be used to direct heat into or away from the snow. Melt out date can be moved forward or backward 2 weeks to 1 month by increase or decrease of forest cover (Smith 1974, 1975).

While wind distribution plays little role in this province, differential melt is substantial. The greater amount of snow in forest openings on the west-south walls were once thought to be the result of distribution; it has since been found to be the result of greater melt on the north and east side of the opening (Smith 1974).

Forest interception has been found to have little influence on snow placement under lodgepole; but under red fir and other conical-shaped crowns, the snow caught while the branches were extended depresses the crowns, and snow is deposited near the tree stem where it may differentially melt (Smith 1974). This accounts for the previous findings that only 65 percent of snow which fell in the open was found in the forest. At one time it was believed that much of this was lost to evaporation. It has since been found that evaporation accounts for less than 2 area-inches over such areas that have half their area in forest and half in open.

LIMITATIONS AND PRECAUTIONS: PROBLEMS ASSOCIATED WITH HYDROLOGIC MODELING FOR SNOW REGIONS

There are more problems associated with modeling the hydrologic responses of snow covered basins than with modeling those subject to rainfall.

Snowfall redistributes the precipitation in time and occasionally in space. Snow falling in the Rocky Mountains is not reflected in the soil moisture or streamflow until spring melt. In the Pacific Coast province it may appear as soil moisture or streamflow within a few days, or it may not appear until spring. Due to lack of ice lenses, melt or rain falling on snow in this region may enter the soil under a forest growing on a south slope. Removal of the forest may result in ice lens formation in the pack, and rain or melt may flow through the snow to the stream and never reach the soil to provide water for satisfaction of soil water deficit.

Soils are youthful and very porous, thus resulting in rapid drainage of surplus water following snowmelt. Since summers are usually long and without precipitation, early snowmelt results in a lengthening of the drought season.

PROCEDURAL FLOW CHART

Evapotranspiration for snow dominated regions is estimated using precipitation and energy relationships with subsequent adjustments made for snow redistribution and vegetation cover density. The difference between precipitation and evapotranspiration becomes water available for streamflow if changes in soil moisture storage are negligible.

The flow chart in figure III.23 outlines the methodology procedure for estimation of potential streamflow. Worksheets III.5 and III.6 have been constructed to facilitate calculations.

Explanation of the flow chart follows.

HYDROLOGIC REGION OR PROVINCE

Based on the preceding discussion, select the region which most closely characterizes the site.

CONDITION

The condition or point in time for which each analysis is to be made must be specified. Condition can represent baseline, existing (if different from baseline) or proposed. The following discussion centers on two conditions—existing and proposed—primarily to evaluate impact of planned activities; but the methodology is flexible and a variety of conditions could be considered. The methodology is looped so that procedural steps return to this point after both evapotranspiration and water available for streamflow have been calculated for each condition.

ENERGY ASPECT

One of the first criteria for subdividing the watershed or management unit is aspect. Energy so strongly controls snow processes that the major criterion for subdivision is the energy class for differing aspects.

Several aspect and elevation zones were combined into three basic energy levels. The energy aspects were defined as:

1. High energy-low elevation aspects (low, south aspects)
2. Intermediate energy aspects
    a. Low to mid-elevation north, east, and west aspects
    b. High elevation south aspects
3. Low energy-high elevation aspects (high elevation north, east, and west aspects)

The significance of classifying by aspect is, of course, in terms of energy available to melt snow and to evapotranspire water. The elevation and aspect of a site must be determined and placed in one of the three energy aspects for use in further analysis (item 4).

SILVICULTURAL PRESCRIPTION

For each condition, divide the energy aspect or management unit into subunits based on silvicultural prescription. The prescription should be uniform for each subunit and may be uniform for the entire energy aspect. By the same token, the silvicultural prescription can be uniform (forested) for one condition (existing) and varied (clearcut, thinned) for another. Silvicultural prescription designations allow flexibility to subdivide the energy aspect into subunits based on significant silvicultural or hydrological characteristics of either the site or the prescriptions. This implies subdivision based not only on silvicultural practice, but also on uniform soil depth and aspect.

SEASON

Evapotranspiration is calculated by season, and seasonal dates can vary by region. In the modeling effort, selection of seasonal dates for each region and province was based on simulated precipitation/streamflow relations. Basically, the intent was to isolate the fall, the winter (period of snowpack development and melt), and the growing season. The season is entered in item (9).

In the Rocky Mountain/Inland Intermountain region (4) and in the Continental/Maritime province (6), seasonal evapotranspiration is presented for three increments of time as follows:

Winter: Oct. 1—Feb. 28
Spring: March 1—June 30
Summer and fall: July 1—Sept. 30

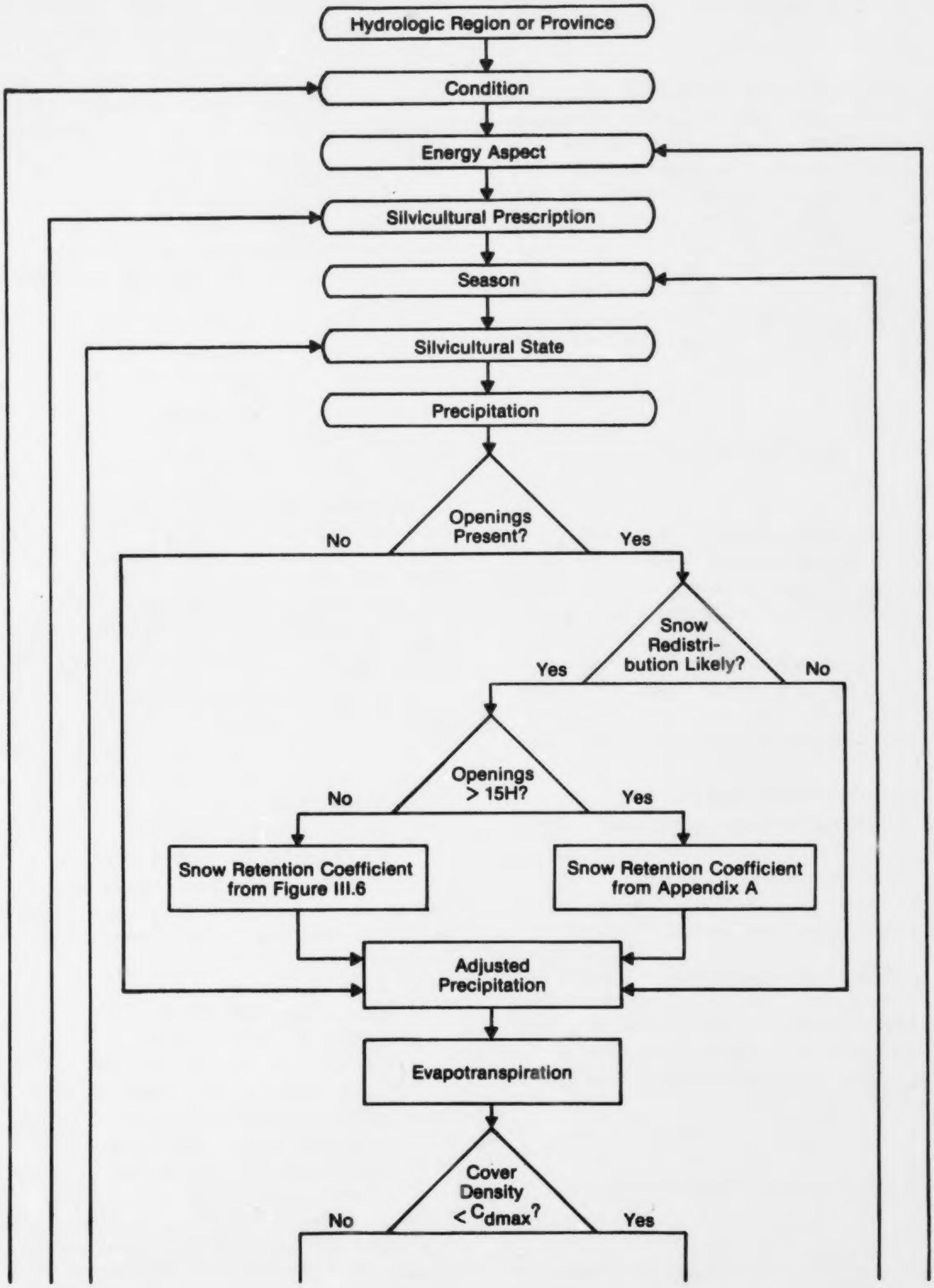
In the Pacific Coast/Central Sierra province (7) and in the Pacific Coast/Northwest province (5), seasonal evapotranspiration is presented for four increments of time:

Early winter: Oct. 1—Dec. 29
Late winter: Dec. 30—Mar. 28
Spring: Mar. 29—June 26
Summer and fall: June 27—Sept. 30

The New England/Lake States region (1) has three seasons, varying slightly from the others:

Fall, early winter: Oct. 1—Jan. 31
Late winter, early spring: Feb. 1—Apr. 30
Growing season: May 1—Sept. 30

The procedure is looped so that evapotranspiration and water available for streamflow are estimated by season within a silvicultural prescription before the next prescription is considered.


Hydrologic Region or Province
Condition
Energy Aspect
Silvicultural Prescription
Season
Silvicultural State
Precipitation
Openings Present?
No
Yes
Snow Redistribution Likely?
Yes
No
Openings > 15H?
No
Yes
Snow Retention Coefficient from Figure III.6
Snow Retention Coefficient from Appendix A
Adjusted Precipitation
Evapotranspiration
Cover Density < C_{dmax}?
No
Yes

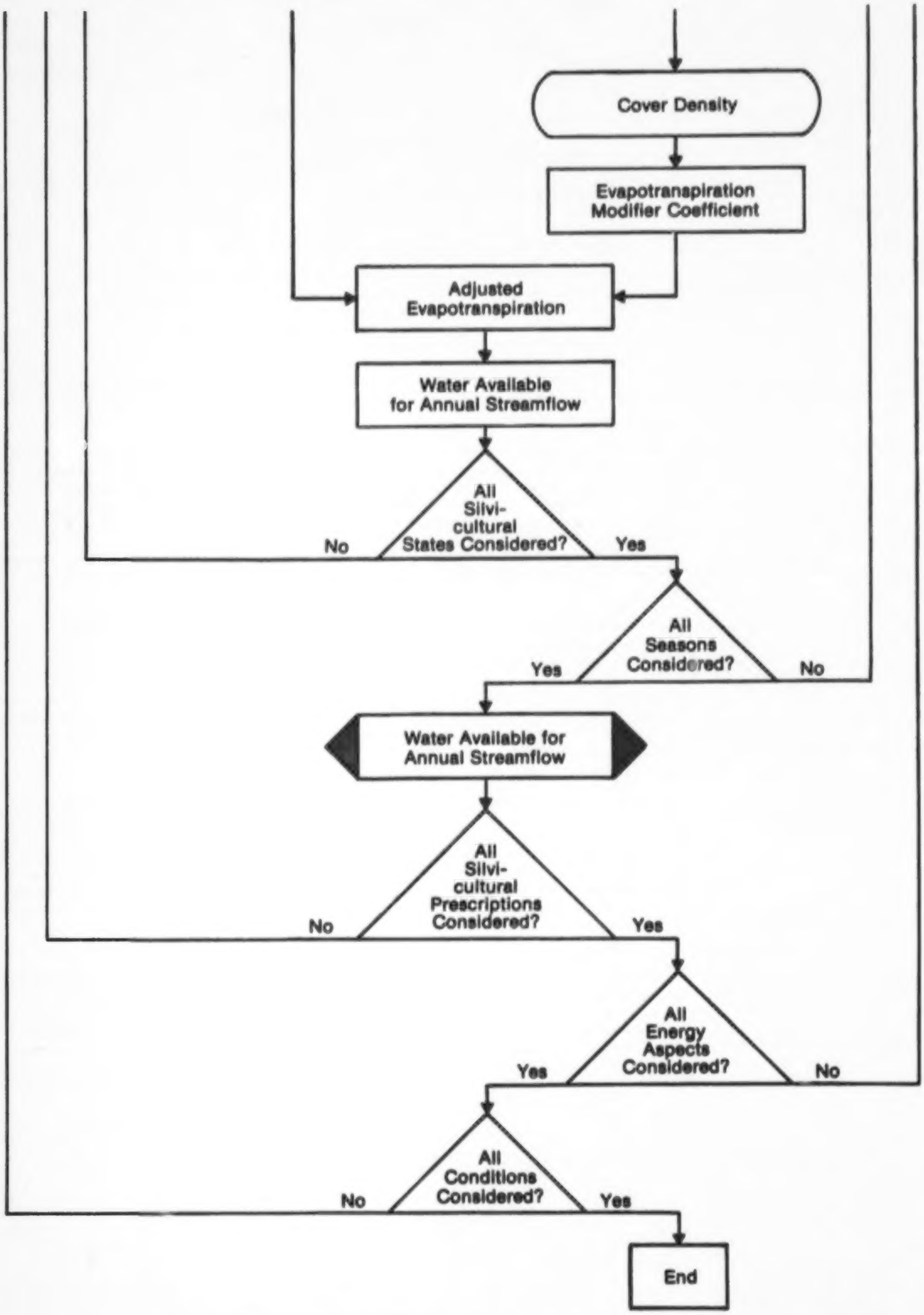

Cover Density
Evapotranspiration Modifier Coefficient
Adjusted Evapotranspiration
Water Available for Annual Streamflow
All Silvi-cultural States Considered?
No
Yes
All Seasons Considered?
Yes
No
Water Available for Annual Streamflow
All Silvi-cultural Prescriptions Considered?
No
Yes
All Energy Aspects Considered?
Yes
No
All Conditions Considered?
No
Yes
End

Figure III.23.—Flow chart of methodology for determining water available for annual streamflow, snow dominated regions.

WORKSHEET

Water available for streamflow for the

(1) Watershed name____________________ (2) Hydrologic region____________________

(5) Vegetation type____________________ (6) Annual precipitation____________________

Season name/dates (9)	Silvicultural prescription		Area		Precipitation (in) (14)	Snow retention coef. (15)	Adjusted snow retention coef. (16)	Adjusted precipitation (in) (17)
	Compartment (10)	Silvicultural state (11)	Acres (12)	% (13)				
	Unimpacted							
	Impacted							
	Total for season							
	Unimpacted							
	Impacted							
	Total for season							
	Unimpacted							
	Impacted							
	Total for season							
	Unimpacted							
	Impacted							
	Total for season							

Water available for annual streamflow (in)	Unimpacted	(30)
		(31)
	Impacted	(32)
		(33)
		(34)
		(35)

III.5

existing condition in snow dominated regions

(3) Total watershed area (acres) ____________________ (4) Dominant energy-aspect ______________________

(7) Windward length of open area (tree heights) __________ (8) Tree height (feet) ______________________

ET (in) (18)	Basal area (ft²/ac) (19)	Cover density		ET modifier coef. (22)	Adjusted ET (in) (23)	Water available for streamflow (in)					
		% (20)	$\%C_{dmax}$ (21)			(24)	(25)	(26)	(27)	(28)	(29)

Notes for Worksheet III.5

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in the text.
(3)-(8)	User supplied.
(9)	Seasons for each hydrologic region are described in the text.
(10)	The unimpacted compartment includes areas not affected by silvicultural activity. The impacted compartment includes areas affected by silvicultural activity. Impacted areas do not have to be physically disturbed by the silvicultural activity. For example, if an area is subject to snow redistribution due to a silvicultural activity, it is an impacted area.
(11)	Areas of similar hydrologic response as identified and delineated by vegetation or silvicultural activity.
(12)	User supplied.
(13)	Column (12) ÷ item (3).
(14)	User supplied.
(15)	From figure III.6 or appendix A or user supplied.
(16)	Snow retention coefficient adjustment for open areas:

$$\rho_{oadj} = 1 + (\rho_o - 1)\left(\frac{.50}{X}\right)$$

where:

ρ_{oadj} = adjusted snow retention coefficient for open areas (receiving areas)

ρ_o = snow retention coefficient for open areas

$X = \frac{\text{open area (in acres)}}{\text{impacted area (in acres)}}$

Snow retention coefficient adjustment for forested source areas (impacted forest areas):

$$\rho_f = \frac{1-\rho_{oadj}\,X}{1-X}$$

where:

ρ_f = adjusted snow retention coefficient for areas affected by snow redistribution (source areas)

$$X = \frac{\text{open area (in acres)}}{\text{impacted area (in acres)}}$$

(17) Column (14) x column (16)

(18) From figures III.24 to III.40 or user supplied.

(19) User supplied (not required if % cover density is user supplied).

(20) From figures III.41 to III.45 or user supplied.

(21) (Column (20) ÷ C_{dmax}) x 100 where C_{dmax} is the % cover density required for complete hydrologic utilization. C_{dmax} is determined by professional judgment at the site.

(22) From figures III.46 to III.56.

(23) Column (18) x column (22).

(24)-(29) The quanitity [column (17)-column (23)] x column (13).

(30) Sum of column (24).

(31) Sum of column (25).

(32) Sum of column (26).

(33) Sum of column (27).

(34) Sum of column (28).

(35) Sum of column (29).

WORKSHEET

Water available for streamflow for the

(1) Watershed name____________________ (2) Hydrologic region____________________

(5) Vegetation type____________________ (6) Annual precipitation____________________

Season name/dates (9)	Silvicultural prescription		Area		Precipitation (in) (14)	Snow retention coef. (15)	Adjusted snow retention coef. (16)	Adjusted precipitation (in) (17)
	Compartment (10)	Silvicultural state (11)	Acres (12)	% (13)				
	Unimpacted							
	Impacted							
	Total for season							
	Unimpacted							
	Impacted							
	Total for season							
	Unimpacted							
	Impacted							
	Total for season							
	Unimpacted							
	Impacted							
	Total for season							

Water available for annual streamflow (in)	Unimpacted	(30)
		(31)
	Impacted	(32)
		(33)
		(34)
		(35)

III.6

proposed condition in snow dominated regions

(3) Total watershed area (acres)____________________ (4) Dominant energy-aspect______________________

(7) Windward length of open area (tree heights)___________ (8) Tree height (feet)______________________

ET (in) (18)	Basal area (ft^2/ac) (19)	Cover density		ET modifier coef. (22)	Adjusted ET (in) (23)	Water available for streamflow (in)					
		% (20)	%C_{dmax} (21)			(24)	(25)	(26)	(27)	(28)	(29)

Notes for Worksheet III.6

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in the text.
(3)-(8)	User supplied.
(9)	Seasons for each hydrologic region are described in the text.
(10)	The unimpacted compartment includes areas not affected by silvicultural activity. The impacted compartment includes areas affected by silvicultural activity. Impacted areas do not have to be physically disturbed by the silvicultural activity. For example, if an area is subject to snow redistribution due to a silvicultural activity, it is an impacted area.
(11)	Areas of similar hydrologic response as identified and delineated by vegetation or silvicultural activity.
(12)	User supplied.
(13)	Column (12) ÷ item (3).
(14)	User supplied.
(15)	From figure III.6 or appendix A or user supplied.
(16)	Snow retention coefficient adjustment for open areas:

$$\rho_{oadj} = 1 + (\rho_o - 1)\left(\frac{.50}{X}\right)$$

where:

ρ_{oadj} = adjusted snow retention coefficient for open areas (receiving areas)

ρ_o = snow retention coefficient for open areas

$X = \frac{\text{open area (in acres)}}{\text{impacted area (in acres)}}$

Snow retention coefficient adjustment for forested source areas (impacted forest areas):

$$\rho_f = \frac{1-\rho_{oadj}X}{1-X}$$

where:

ρ_f = adjusted snow retention coefficient for areas affected by snow redistribution (source areas)

$$X = \frac{\text{open area (in acres)}}{\text{impacted area (in acres)}}$$

(17) Column (14) x column (16)

(18) From figures III.24 to III.40 or user supplied.

(19) User supplied (not required if % cover density is user supplied).

(20) From figures III.41 to III.45 or user supplied.

(21) (Column (20) ÷ C_{dmax}) x 100 where C_{dmax} is the % cover density required for complete hydrologic utilization. C_{dmax} is determined by professional judgment at the site.

(22) From figures III.46 to III.56.

(23) Column (18) x column (22).

(24)-(29) The quanitity [column (17)-column (23)] x column (13).

(30) Sum of column (24).

(31) Sum of column (25).

(32) Sum of column (26).

(33) Sum of column (27).

(34) Sum of column (28).

(35) Sum of column (29).

SILVICULTURAL STATE

In order to assess the overall hydrologic effect of silvicultural prescriptions on streamflow, each area receiving different treatments is considered individually (items 10 and 11). The summation of hydrologic effects in each treatment area yields an overall effect for the prescription. Treatment areas are delineated and grouped to reflect similar hydrologic response. For example, large open areas may be grouped, small open areas may be grouped, forested areas may be grouped. Hydrologic response is related to the type and quantity of vegetation at a site as well as to physical factors such as slope, soil texture, solar radiation, and precipitation regime. In snow dominated regions, cover density (C_d) and snow redistribution are major criteria used for identification and delineation of silvicultural activity areas. Cover density and snow redistribution are discussed later in this section.

PRECIPITATION

An estimate of precipitation by season (item 14) must be supplied. It may vary by energy aspect. Based on site measurements or extrapolation from other data, the estimate may represent a long-term mean or an extreme value, depending upon the objectives defined.

OPENINGS PRESENT?

In some areas in which the major form of precipitation is snowfall, the meteorological-topographic relationship may not be significant, but in other areas it is. In the Rocky Mountain/Intermountain region, for example, snowfall is the dominant form of precipitation and windblown snow dominates the regime. In this area, when the forest cover is removed through spatially distributed openings, snowfall distribution is changed. If snow redistribution is not a factor, or if openings are not present, precipitation need not be adjusted and gross precipitation should be considered synonomous with "adjusted precipitation."

If openings are present, it must be considered if snow redistribution is likely.

SNOW REDISTRIBUTION LIKELY?

As noted, precipitation characteristics in some regions are such that the creation of openings can significantly alter snow distribution, while in other regions this is not the case. If openings are considered not to affect snow distribution (answer = no) the precipitation estimate made above is considered to be the adjusted precipitation. If openings can affect distribution then sizes must be evaluated since this influences redistribution characteristics.

OPENING >15H?

The aerodynamic change in roughness of the vegetative surface modifies patterns of snow accumulation so that more snow may accumulate in the cutover area and less in the uncut forest.

Objective methods for quantifying the universality of the effects of silvicultural activities on snow redistribution through snowblowing are not yet available; quantification of these effects must be based on considerable judgment and experience in a particular area.

Significant increases in snow accumulation near the center of small forest openings—less than 15H in diameter (H = height of surrounding trees) — are substantially offset by decreases in snowpack below the undisturbed forest so that total snow storage on watersheds subjected cutting is not changed. For openings less than 15H, determine the redistribution coefficient directly from figure III.6. When openings are large — greater than 15H in diameter — however, total watershed snow storage may be decreased through large sublimation losses and transport of snow out of the basin (see fig. III.6 for approximate effect). Openings greater than 15H in diameter or greater than 15H in windward length produce a more complex snow redistribution than smaller openings. A detailed discussion of snow redistribution for openings greater than 15H is presented in appendix III.A.

Depending upon the average size of the openings in the silvicultural state, obtain a retention coefficient from figure III.6, appendix III.A. or local derivation, and proceed to determining the adjusted snow retention coefficient.

SNOW RETENTION COEFFICIENT FROM FIGURE III.6

For clearcuts less than 15H in diameter or in windward length, the snow retention coefficient (item 15) may be found on figure III.6. A representative average length or diameter can be applied to a watershed with openings of varying diameters or windward lengths. Alternately, if greater resolution is required, the watershed can be subdivided so that openings can be handled individually or in groups.

Any large retention of snow as a result of forest cutting can be an important factor in determining the amount of runoff. For example, in the lodgepole pine type in Colorado, this redistribution effect is not greatly diminished 30 years after timber harvest, in spite of regrowth of trees and associated increase in forest cover density. It is thought that changes in natural snow accumulation patterns produced by timber harvest will persist until the new crop of trees approaches the height of the remaining undisturbed forest.

The significance of the snow retention coefficient (ρ) lies in the opportunity that exists for both decreasing the net water loss from the pack and for altering the melt rate. As already noted, it can be expected that the transpiration losses in the openings will be decreased following cutting. By placing a greater percentage of the total snowpack in these openings and less in the residual forest, the exposure of the net precipitation (in this case, snow) to evapotranspirational processes can be reduced. Because this snow is redistributed and because cover conditions have been altered, a significantly greater proportion of the pack is exposed to sunlight, and differing melt rates can be expected.

In contrast, as the size of the opening increases beyond 15H, the opportunity for increased ablation losses and wind scour reduces the net precipitation below pre-silvicultural activity levels. This effect is significant since it represents a net loss in water input to the system.

In old-growth subalpine forest, optimum redistribution of snow occurs when the stand is (1) harvested in small patches of less than 5H in diameter; (2) the patch cuts are protected from wind; and (3) the patches are interspersed at least 5 to 8H apart.

In regard to redistribution of a finite amount of snow, in openings less than 15H there is a contributing area for increases occurring in the openings. The area of contribution is about equal to the area of the opening; therefore, if the openings occupy more than 50 percent of the area, redistribution will be less efficient. In these situations ρ_o would have to be adjusted to reflect the limiting contributing area. If the area cut exceeds 50 percent, the following adjustment in ρ_o can be used:

$$\rho_{o\,adj} = 1 + (\rho_o - 1)\,(.50/X) \qquad \text{(III.3)}$$

$$X = \frac{\text{open area}}{\text{total impacted area}}$$

It should be emphasized that the redistribution theory does not require adjustment when timber is harvested in small patches which occupy less than 50 percent of the watershed. In this case $\rho_o = \rho_{oadj}$ since ρ_{oadj} is used in the following equation. The snow retention coefficient for the residual forest stand (ρ_f) is calculated and weighted as follows:

$$\rho_f = \frac{1 - \rho_{o\,adj}X}{1 - X} \qquad \text{(III.13)}$$

where:

ρ_f = adjusted snow retention coefficient for forested areas affected by snow redistribution

ρ_{oadj} = adjusted snow retention coefficient for open area (item 16)

The snow retention coefficient for the forested impacted area is calculated under the assumption that a silvicultural activity causes no net increase or decrease of snow on the impacted area. Total impacted area in snow dominated regions includes areas affected by a silvicultural activity either directly or indirectly. These effects may involve snow redistribution and evapotranspiration.

SNOW RETENTION COEFFICIENT FROM APPENDIX A

The procedure for calculation of snow retention coefficients for openings larger than 15H in diameter or windward length is found in appendix III.A.

ADJUSTED PRECIPITATION

Adjusted seasonal precipitation (item 17) for a silvicultural state is obtained by multiplying seasonal precipitation (supplied by the user) by the adjusted snow retention coefficient for that area. If snow distribution is not significant for an activity area, the snow retention coefficient is 1.0. The estimates of precipiation, corrected for treatment are now used to estimate site specific evapotranspiration.

EVAPOTRANSPIRATION

Analysis of several hundred station years of records simulated by the Subalpine Water Balance Model (Leaf and Brink 1973) has shown that seasonal evapotranspiration (item 18) can be expressed as a function of seasonal precipitation. In some areas the data base did not encompass precipitation levels which would result in limiting the evapotranspiration level, and for these regions the potential effect has been estimated. Since much of the area affected by snowpack development is close to being arid, the baseline level of evapotranspiration can be limited by insufficient precipitation.

The evapotranspiration/precipitation relationships developed for the Rocky Mountain/Inland Intermountain hydrologic region (4) are plotted on figures III.24 to III.26. Unlike the presentation for rain dominated regimes, the relationships are presented as functions of seasonal precipitation by energy aspect zones.

Similar relationships for the other hydrologic regions follow:

Pacific Coast — Northwest (5) on figures III.27 to III.30

Continental/Maritime (6) provinces on figures III.31 to III.33

Central Sierra (7) on figures III.34 to III.37

New England/Lake States (1) on figures III.38 to III.40.

It can be noted that simulated evapotranspiration is strongly precipitation dependent at low precipitation levels.

Consulting these figures (III.24 to III.40), it is possible to estimate baseline evapotranspiration for a given precipitation regime. The curves represent normalized averages based on simulations. If more accurate baseline estimates of actual or potential evapotranspiration can be supplied, these may be more representative of a specific site. The input required is an estimate of seasonal precipitation from which evapotranspiration can be estimated.

One apparent discrepancy can be noted. A close inspection of the curves reveals that, for those seasons in which evapotranspiration is precipitation dependent, the change in ET per unit change in precipitation may be greater than 1. The curve represents an integrated response and should not be used to evaluate a change in seasonal precipitation alone, as the curves represent dependence not only on seasonal precipitation but on antecedent precipitation as well.

In the Rocky Mountain/Inland Intermountain hydrologic region, the October 1 through February 28 interval (figs. III.24 to III.26) is not precipitation dependent since losses are essentially from interception and evaporation from the snow surface. These losses are aspect dependent, as shown in figures III.24 to III.26. Evapotranspiration losses during the March 1-June 30 interval vary with precipitation below about 12 inches and also depend on aspect. No aspect dependence was found for evapotranspiration losses during the July 1-September 30 interval, as shown in figure III.26.

In the Continental/Maritime province (6), the winter interval was found not to be precipitation dependent, since losses are essentially from interception and snow evaporation. These losses are aspect dependent (figs. III.31 to III.33). Evapotranspiration losses during the March 1-June 30 interval vary with precipitation below about 15 inches, and also depend on aspect. No aspect dependence was found for evapotranspiration losses during the July 1-September 30 interval (fig. III.33).

In the Central Sierra province (7), both the early and late winter intervals were found not to be precipitation dependent, since losses are essentially from interception and evaporation from snow. These losses are aspect dependent as indicated by figures III.34 to III.37. Evapotranspiration losses during the March 29-June 26 interval (fig. III.36) vary with precipitation below about 12 inches, and also depend on aspect. No aspect dependence was found for evapotranspiration

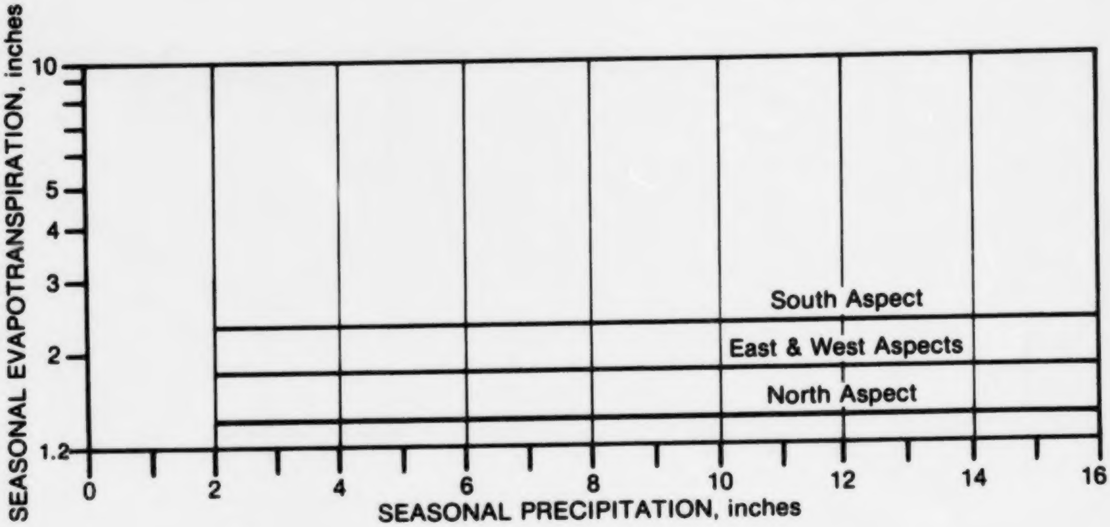


Figure III.24.—Precipitation-evapotranspiration relationships for Rocky Mountain/Inland Intermountain hydrologic region (4), winter season, by energy aspect.

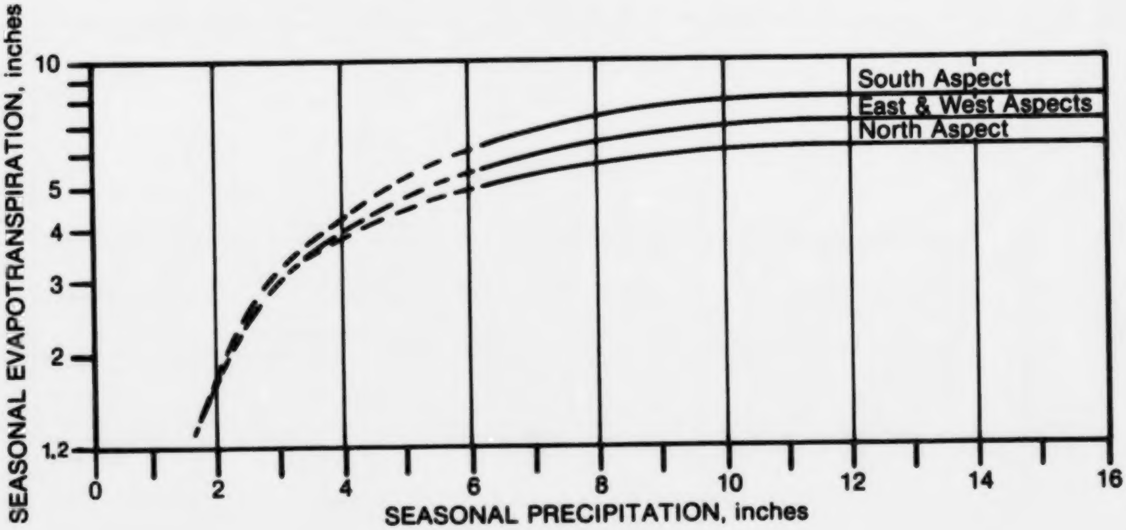


Figure III.25.—Precipitation-evapotranspiration relationships for Rocky Mountain/Inland Intermountain hydrologic region (4), spring season, by energy aspect.

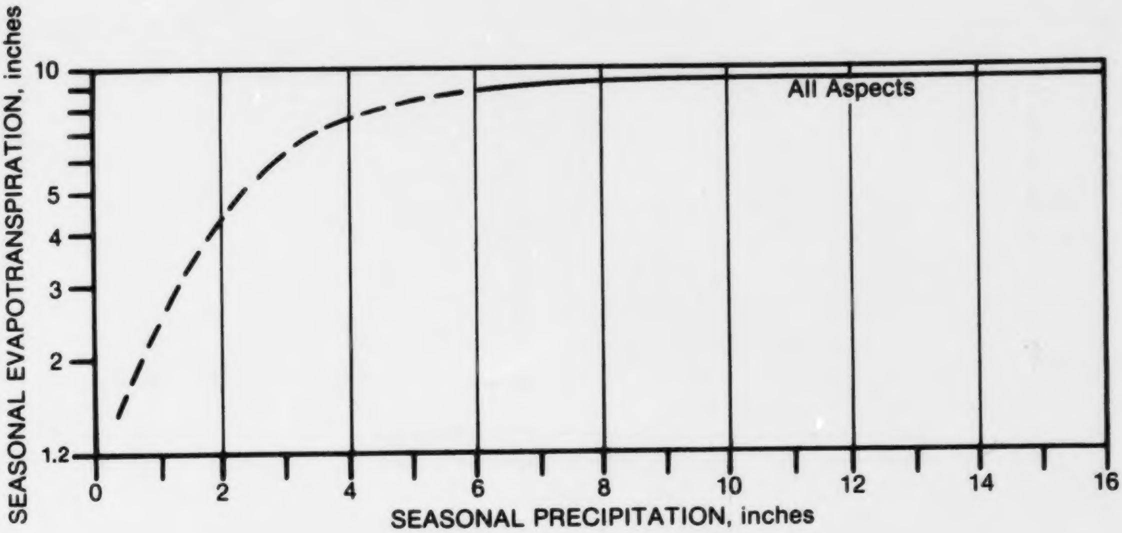


Figure III.26.—Precipitation-evapotranspiration relationships for Rocky Mountain/Inland Intermountain hydrologic region (4), summer and fall season, by energy aspect.

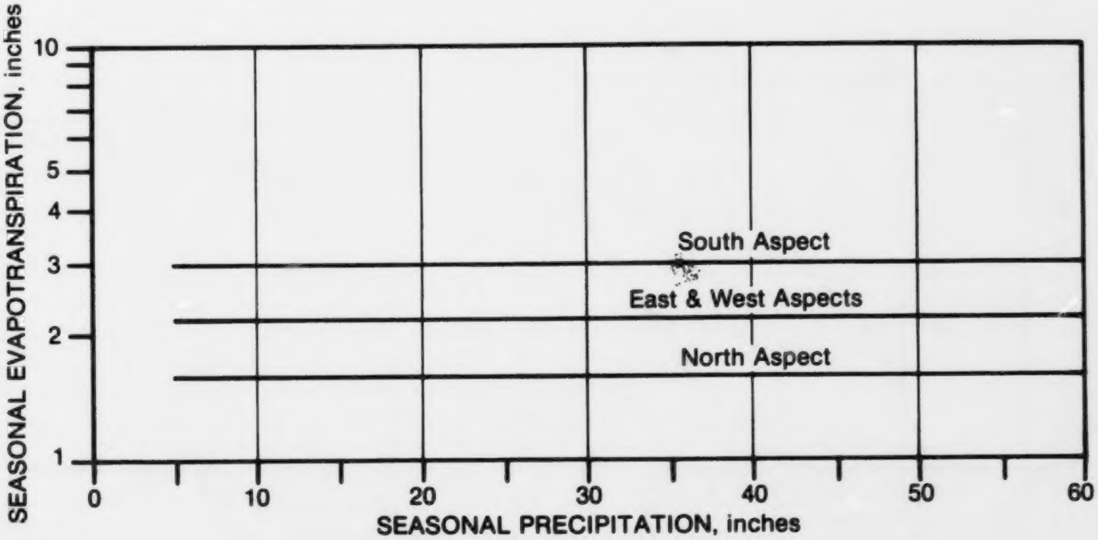


Figure III.27.—Precipitation-evapotranspiration relationships for the Northwest hydrologic province (5), early winter season, by energy aspect.

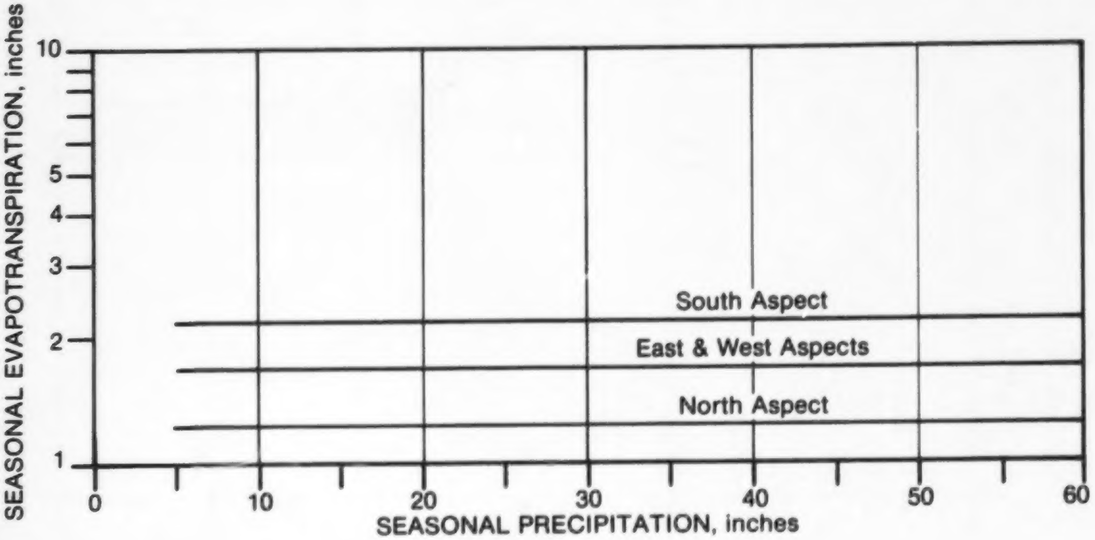


Figure III.28.—Precipitation-evapotranspiration relationships for the Northwest hydrologic province (5), late winter season, by energy aspect.

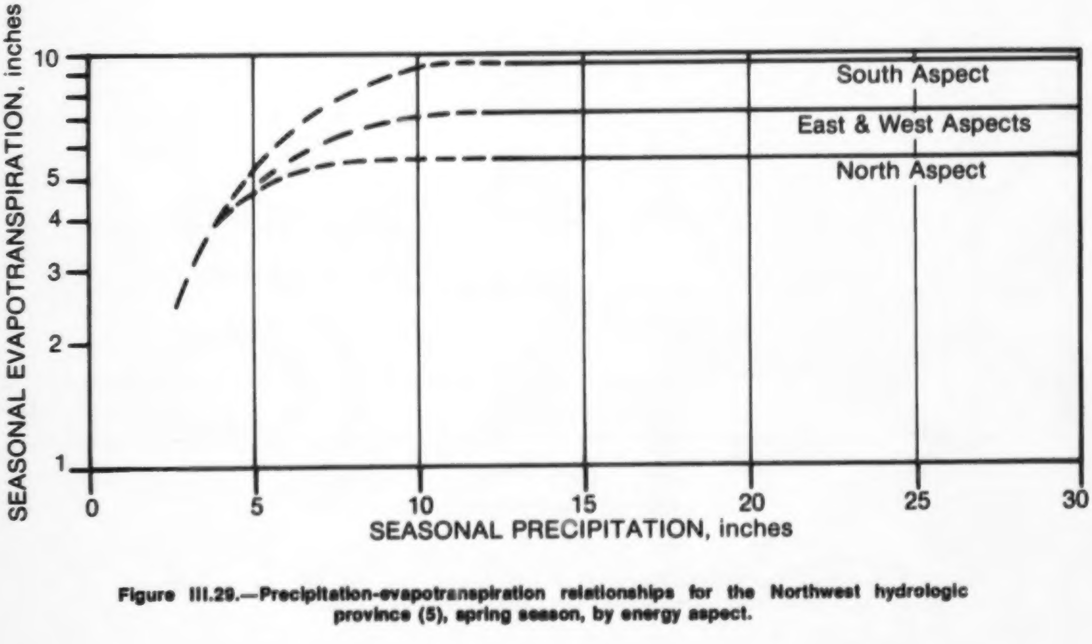


Figure III.29.—Precipitation-evapotranspiration relationships for the Northwest hydrologic province (5), spring season, by energy aspect.

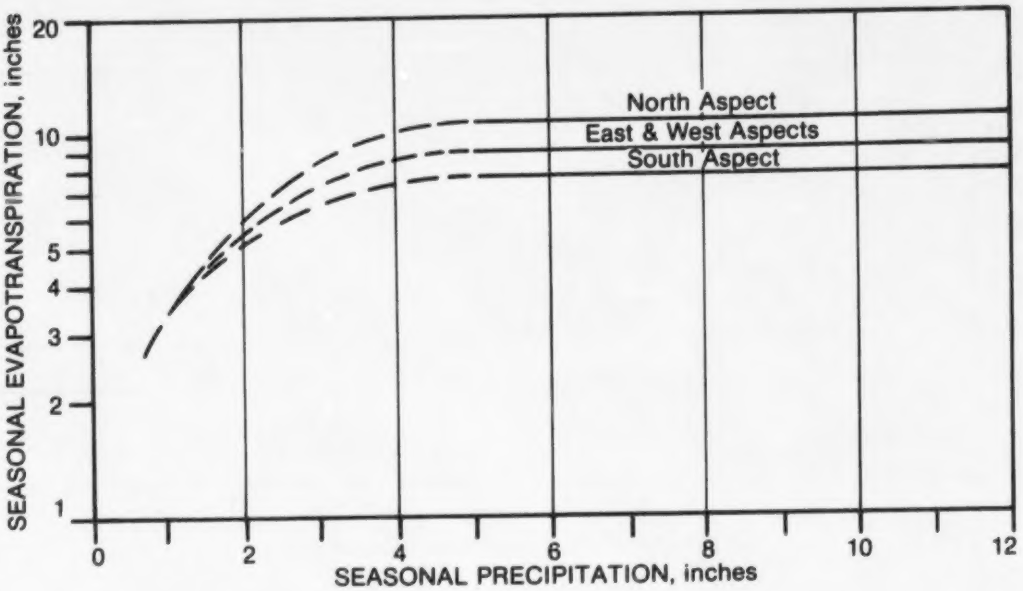


Figure III.30.—Precipitation-evapotranspiration relationships for the Northwest hydrologic province (5), summer and fall season, by energy aspect.

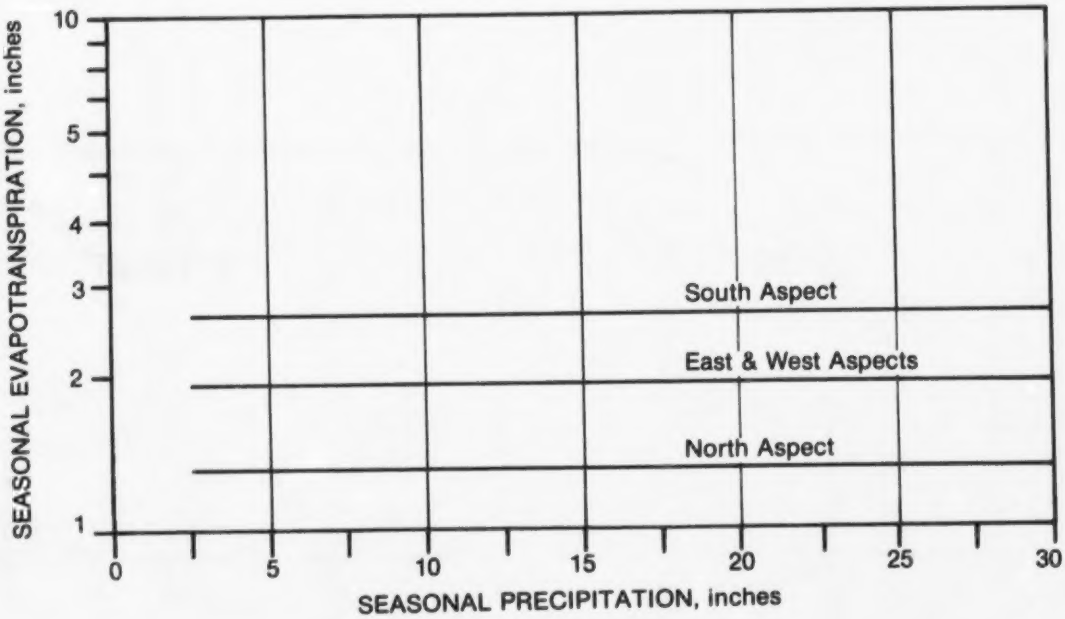


Figure III.31.—Precipitation-evapotranspiration relationships for the Continental/Maritime hydrologic province (6), winter season, by energy aspect.

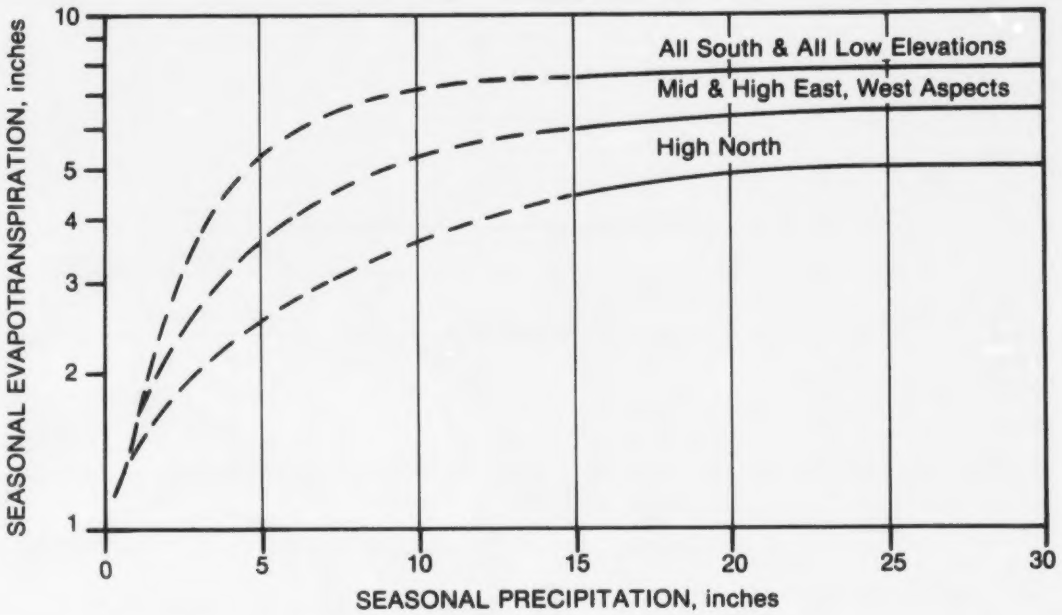


Figure III.32.—Precipitation-evapotranspiration relationships for the Continental/Maritime hydrologic province (6), spring season, by energy aspect.

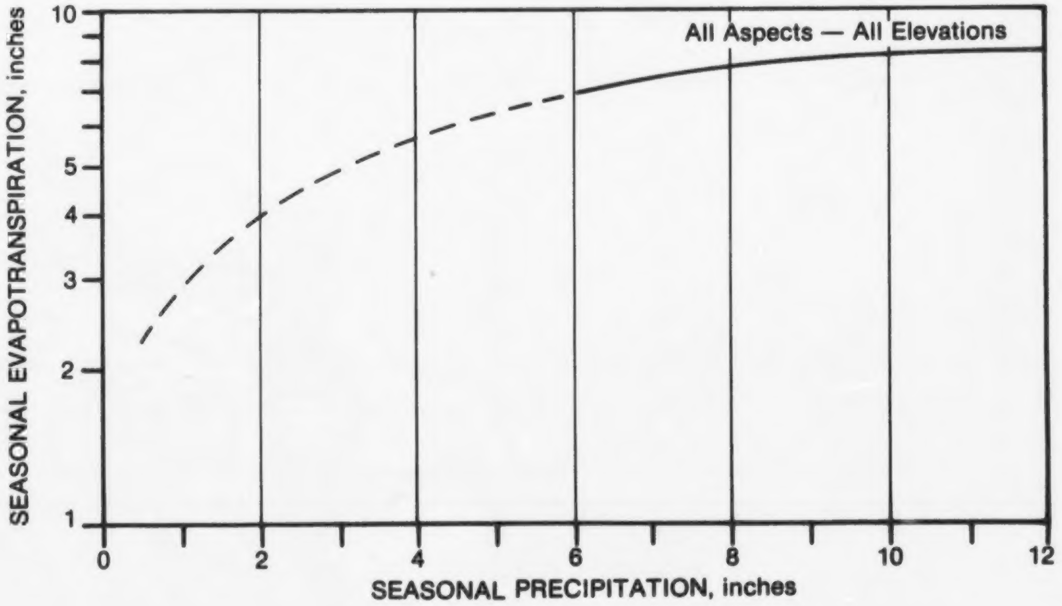


Figure III.33.—Precipitation-evapotranspiration relationships for the Continental/Maritime hydrologic province (6), summer and fall seasons, by energy aspect.

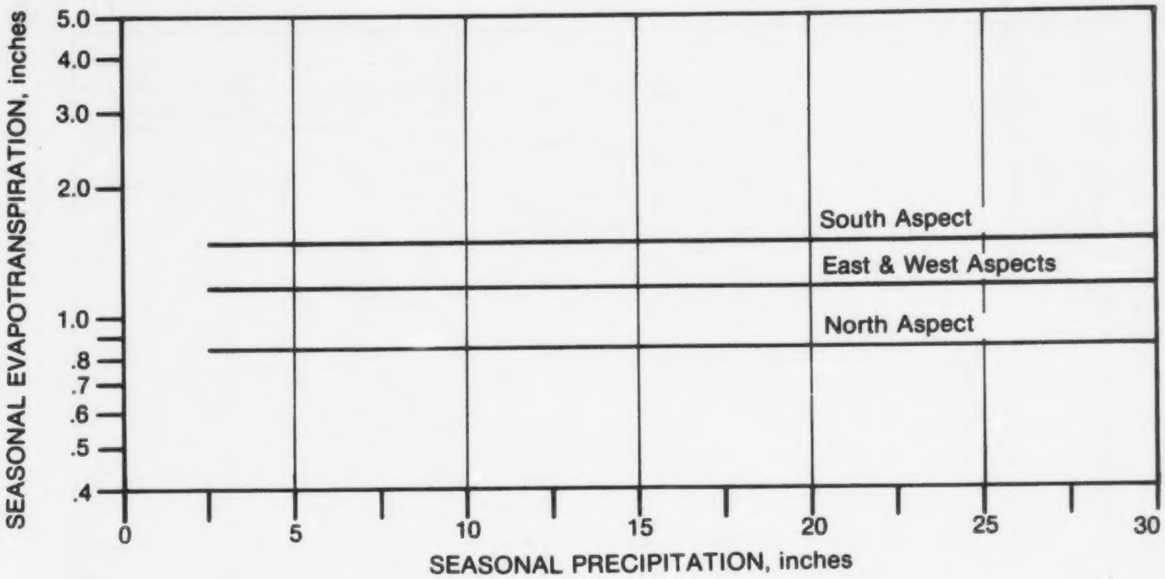


Figure III.34.—Precipitation-evapotranspiration relationships for the Central Sierra hydrologic province (7), winter season, by energy aspect.

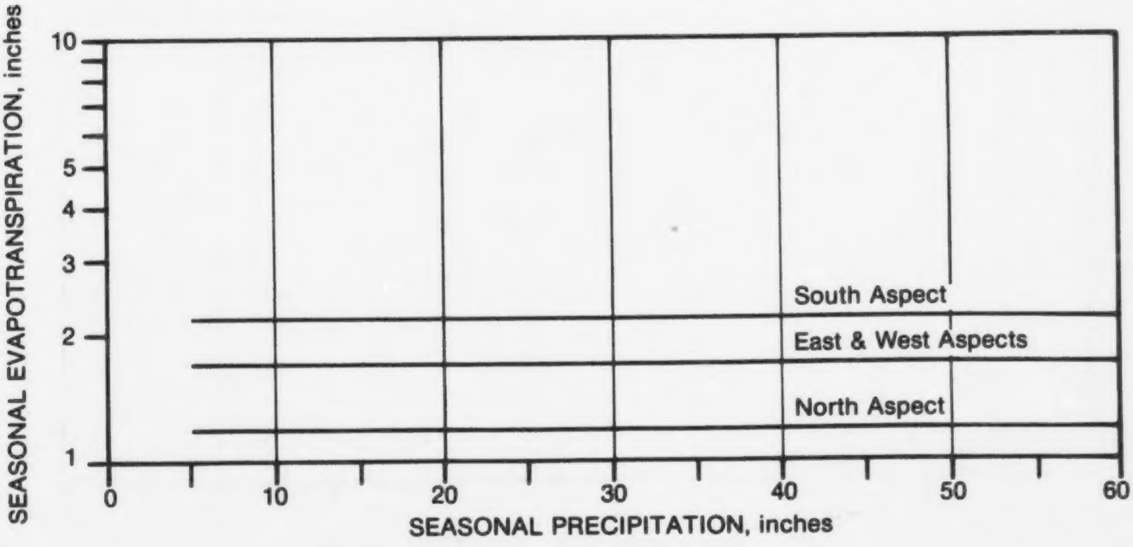


Figure III.35.—Precipitation-evapotranspiration relationships for the Central Sierra hydrologic province (7), late winter season, by energy aspect.

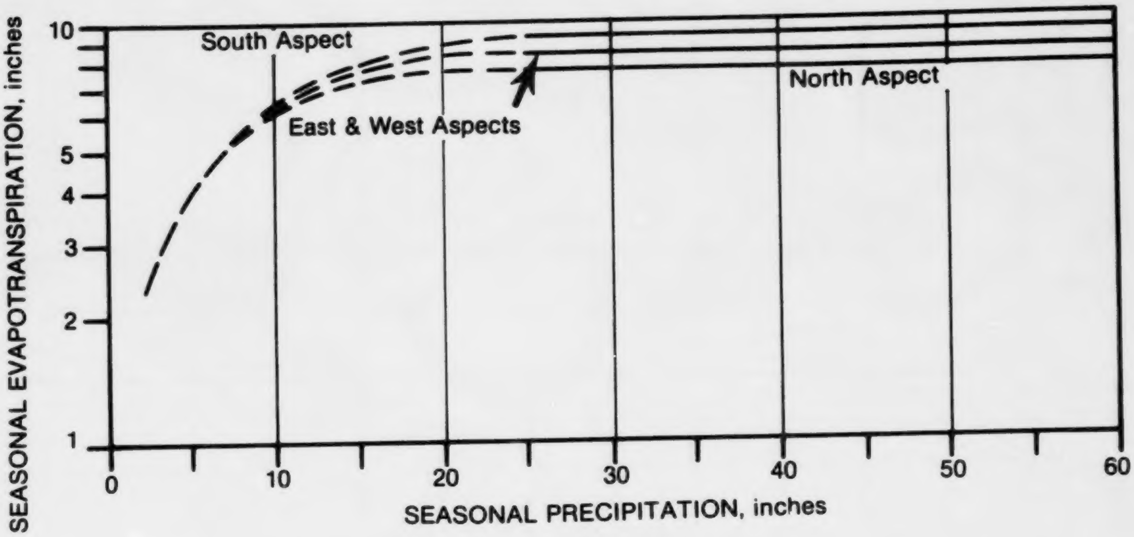


Figure III.36.—Precipitation-evapotranspiration relationships for the Central Sierra hydrologic province (7), spring season, by energy aspect.

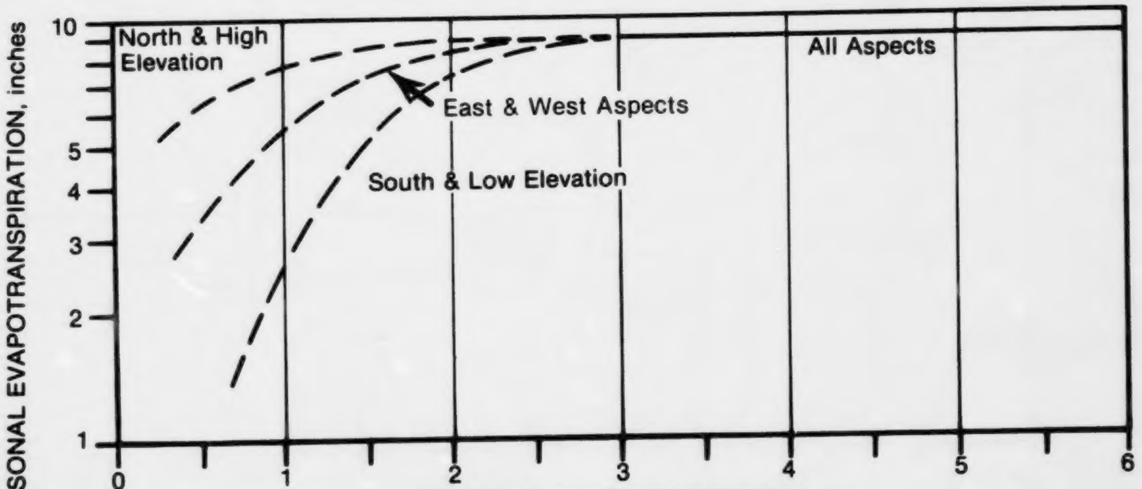


Figure III.37.—Precipitation-evapotranspiration relationships for the Central Sierra hydrologic province (7), summer and fall seasons, by energy aspect.

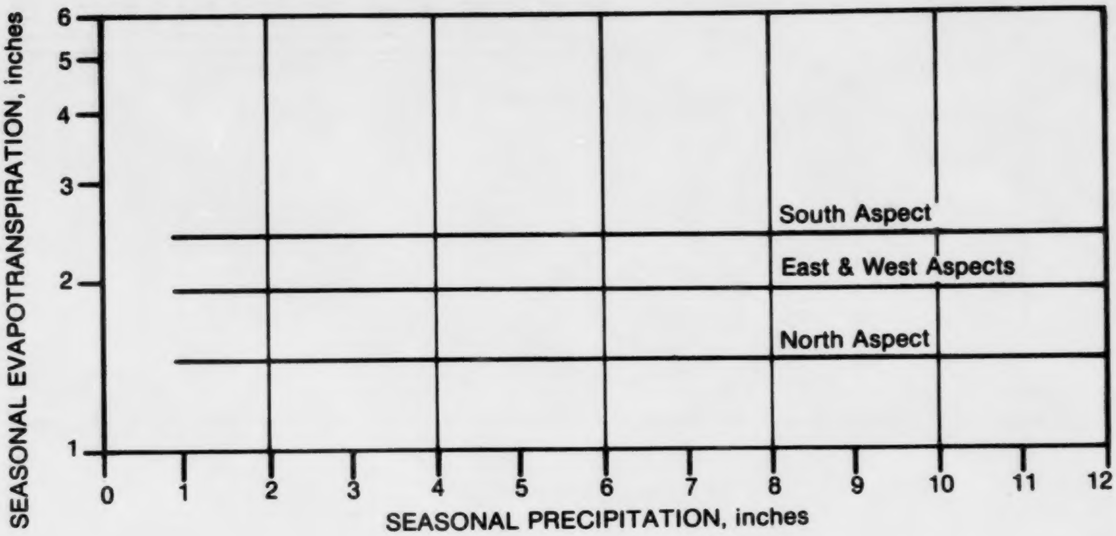


Figure III.38.—Precipitation-evapotranspiration relationships for the New England/Lake States hydrologic region (1), fall-early winter season, by energy aspect.

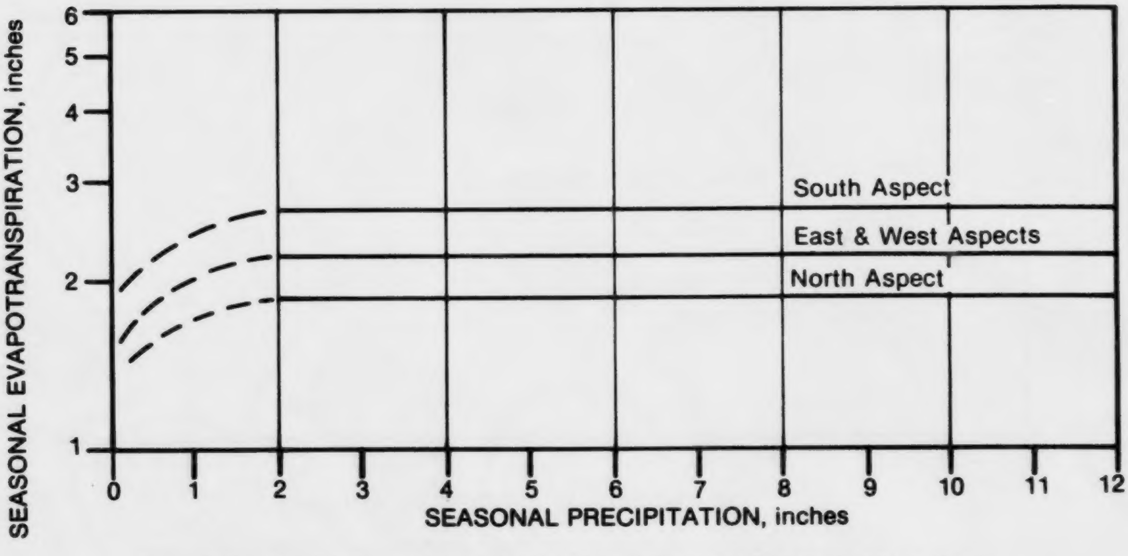


Figure III.39.—Precipitation-evapotranspiration relationships for the New England/Lake States hydrologic region (1), late winter-early spring season, by energy aspect.

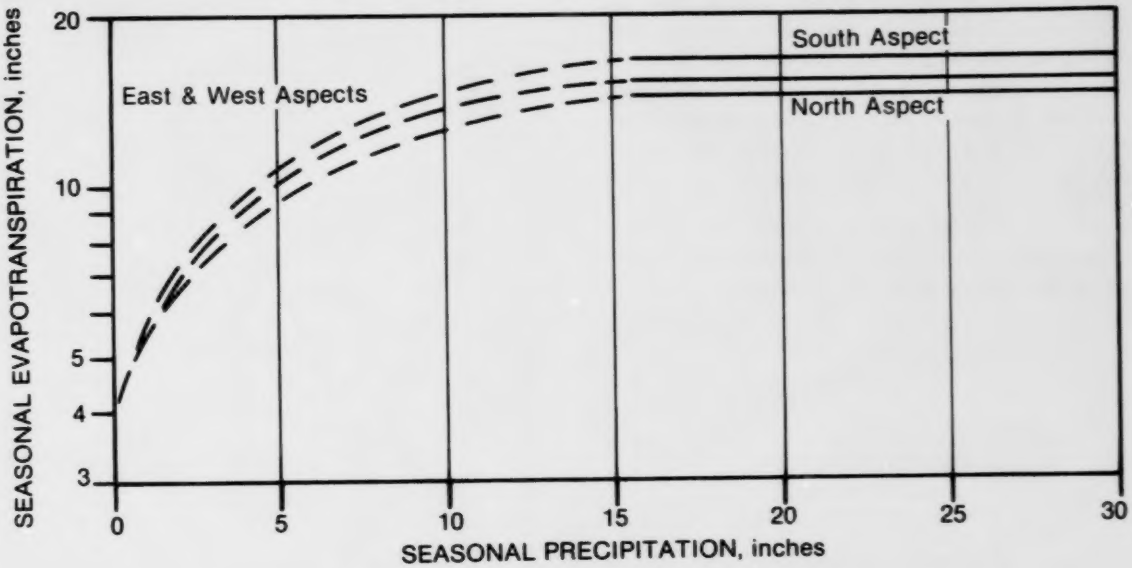


Figure III.40.—Precipitation-evapotranspiration relationships for the New England/Lake States hydrologic region (1), growing season, by energy aspect.

losses during the June 27-September 30 interval (fig. III.37). However, due to the typically dry summer months, soil moisture deficits severely limit evapotranspiration in the lower snow accumulation areas to the south and at low elevations. The low elevation curve of figure III.34 reflects the low evapotranspiration associated with high soil moisture stresses. Where higher snowpacks and later melt seasons provide more residual soil water, evapotranspiration during the summer and fall is markedly higher, as shown in the upper curve.

In the Northwest province, both the early and late winter intervals were found not to be precipitation dependent, and losses are essentially from interception and evaporation from snow. These losses vary with aspect as illustrated in figures III.27 to III.29. Evapotranspiration losses during the March 29-June 26 interval (fig. III.29) vary with precipitation below about 12 inches and also depend on aspect. Aspect dependence was also found for evapotranspiration losses during the June 27-September 30 period (fig. III.30) as well.

In the New England/Lake States hydrologic region, the data base for simulations (fig. III.38 to III.40) did not provide data points for low annual precipitation amounts. In addition, the predominantly wet summers result in an evapotranspiration rate that approaches the potential rate. Compared to western regions, elevation was not considered a significant parameter affecting evapotranspiration. Again, considering the wet growing season, soil depth significantly affecting evapotranspiration was not simulated, except in extremely shallow and/or very coarse-textured soils.

COVER DENSITY $< C_{dmax}$

At this point an estimate of evapotranspiration which assumes cover density is maximum (C_{dmax}) has been obtained. However, maximum cover density may or may not be the case. If it is, the ET estimate is the same as the adjusted ET and the next procedural step is the discussion on adjusted ET. If the cover density is less than maximum, either because of existing conditions or because of proposed activities, an adjustment in ET must be made to allow for the cover density reduction. In either case, it is advisable to review the description of cover density to evaluate the site condition.

The estimates of baseline evapotranspiration presented in figures III.24 to III.40 represent estimates for the full cover density (complete hydrologic utilization). To estimate the impact of a proposed activity or to adjust baseline conditions for past silvicultural activity or history that exists, adjustments must be made to the evapotranspiration values presented in figures III.24 to III.40.

COVER DENSITY

In terms of proposed silvicultural activities or past history, the only significant site parameter that is altered is cover density (item 20). Forest cover density (C_d) is an index which theoretically ranges from zero to less than one, it references the capability of the stand or cover to integrate and utilize the energy input to transpire water. Cover density represents the efficiency of the three-dimensional canopy system to respond to the energy input. It varies according to crown closure, vertical foliage distribution, species, season, and stocking. It is significant in defining the energy transmitted to the ground or the transmissivity coefficient. The cover density and transmissivity coefficient do not add up to one. Some estimates of cover density and transmissivity are listed in table III.2.

Although evapotranspiration is a function of cover density, a silvicultural management plan is not expressed in terms of cover density, but usually, in terms of some parameter such as basal area. Before adjustments in evapotranspiration for the proposed activity can be made, a pre- and post-silvicultural activity cover density estimate must be obtained.

Functions which relate basal areas to forest cover density are plotted in figures III.41 to III.45. These are generalized curves. Pre- and post-silvicultural activity cover density estimates are needed as input to the methodology. If no more accurate data are available, then these figures (III.41 to III.45) may be used as guides in determining the amount of biomass or cover density removed using basal area as an index to management. A note of caution: The curves represent species with a wide range of stand conditions with respect to age and vigor.

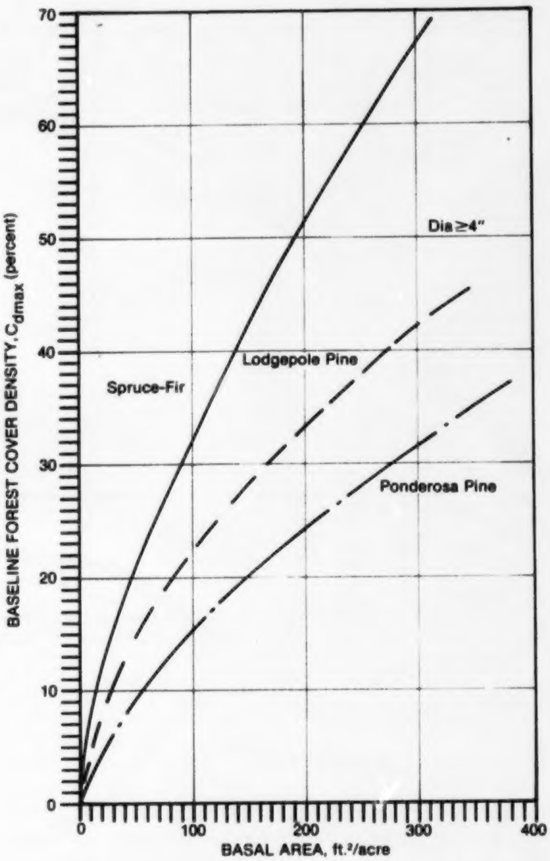


Figure III.41.—Basal area-cover density relationships for the Rocky Mountains/Inland Intermountain hydrologic region (4)—spruce-fir, lodgepole pine, and ponderosa pine for stem diameter ≥ 4 inches dbh.

The following steps are recommended for use of figures III.41 to III.45.

(1) Go to the appropriate basal area-cover density figure with an estimate of existing stand condition (basal area) and determine a cover density.

(2) Then evaluate the morphology of the stand — is it at a point of complete hydrologic utilization for the site? If so, then the cover density estimated represents the maximum cover density (C_{dmax}) for the site.

(3) If past history indicates that the site is not fully occupied, then the cover density determined (C_d) represents existing conditions only; at this point, determine the maximum potential basal area for the site in order to determine the maximum cover density(C_{dmax}).

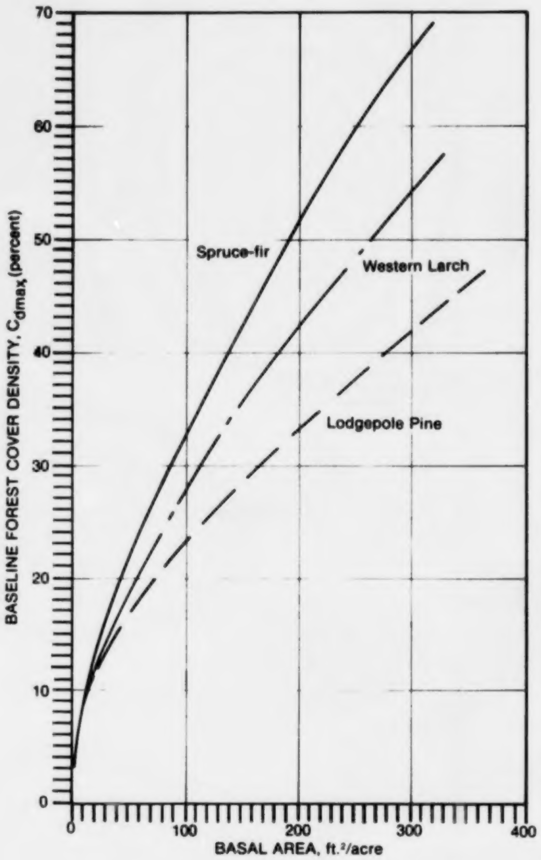


Figure III.42.—Basal area-cover density relationships for the Continental/Maritime hydrologic province (6).

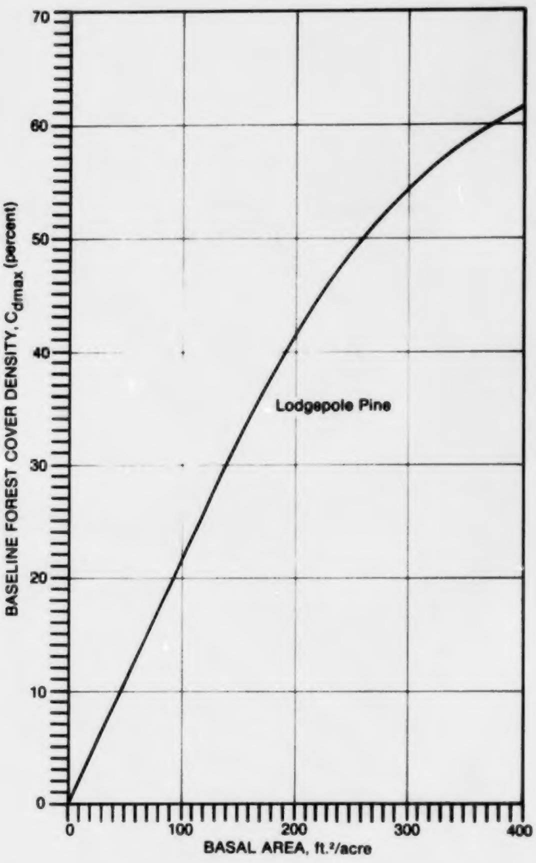


Figure III.43.—Basal area-cover density relationships for the Central Sierra hydrologic province (7).

(4) Once the basal area following the proposed silvicultural activity is determined, return to the figure a second or third time to obtain a post-silvicultural activity cover density.

Baseline conditions or complete hydrologic utilization is represented by maximum cover density (C_{dmax}). Subsequent figures presented in the handbook to determine modifier coefficients for impact adjustments use the ratio of C_d divided by C_{dmax}. In most applications, existing or pre-activity density equals C_{dmax}, but since this is not always the case, an intermediate analysis to define existing conditions may be required.

EVAPOTRANSPIRATION MODIFIER COEFFICIENT

Where an estimate of pre- and post-silvicultural activity cover density for a silvicultural state has been obtained, the next step is to adjust the regional baseline evapotranspiration, given in figures III.26 to III.40. The pre-activity level is the baseline level if past history has not altered the fully forested condition or if the site is in a state of complete hydrologic utilization.

For the Rocky Mountain/Inland Intermountain region, figure III.46 shows modifier coefficients (item 22) for differing levels of forest cover density (C_d). The next step involves application of the coefficients to evapotranspiration for each season to quantify hydrologic impacts resulting from reductions in forest cover density.

Within the Continental/Maritime province, figures III.47 to III.49 represent the modifier coefficients which vary according to forest cover density. Again, equation III.14 involves application of

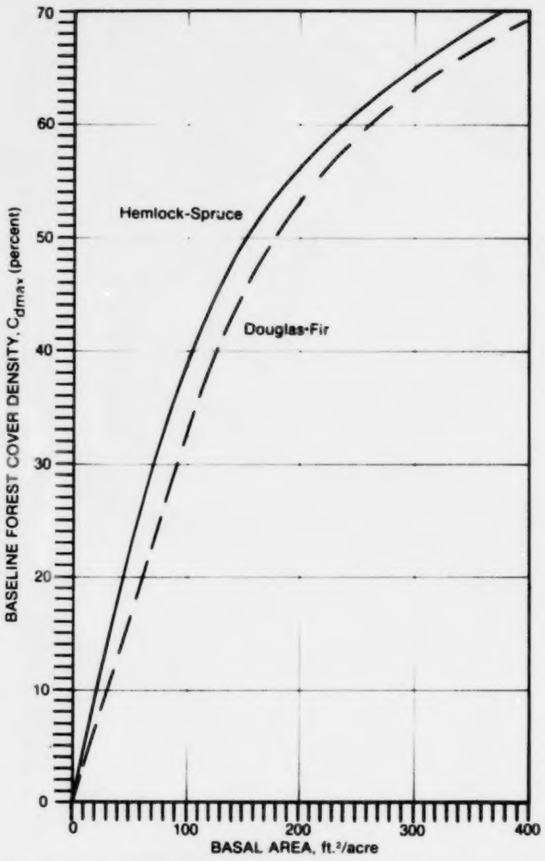


Figure III.44.—Basal area-cover density relationships for the Northwest hydrologic province (5).

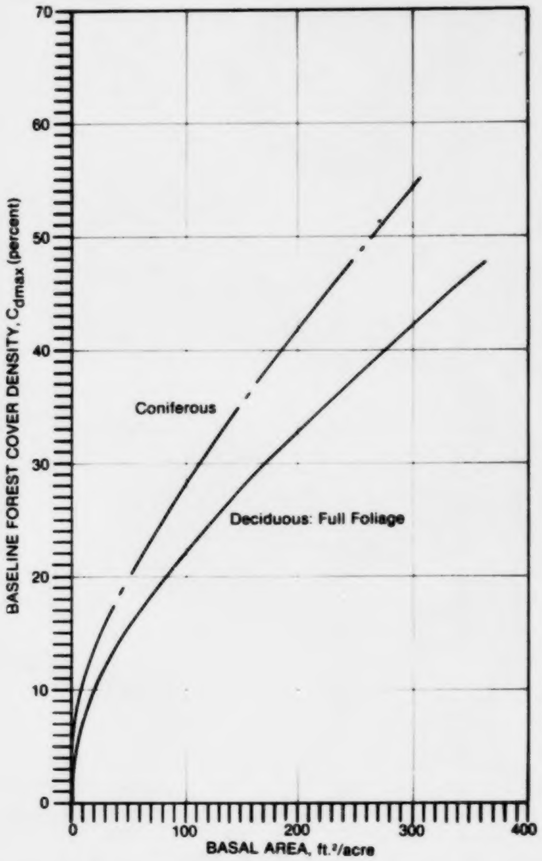


Figure III.45.—Basal area-cover density relationships for the New England/Lake States hydrologic region (1).

the coefficients to baseline evapotranspiration for each of the three seasons to quantify hydrologic impacts resulting from reductions in forest cover density. Two sets of relationships are given for middle and high elevations (figs. III.47 and III.48) and another for low elevations (fig. III.49). The modifier coefficients in figure III.49 are used to adjust baseline evapotranspiration in areas of low seasonal snowpack accumulation.

The modifier coefficients in figure III.49 also apply to montane watersheds in the Rocky Mountain/Inland Intermountain hydrologic region (4). These areas are generally outside the more productive and commercial subalpine forest zone.

In the Central Sierra province, simulations of silvicultural activities were for a 50-percent reduction of the mature forest cover density (C_{dmax}) and 100-percent reduction. Modifier coefficients derived from these simulations are plotted in figures III.50 to III.53. In this province, the modifier coefficient for some seasons (primarily late winter) can exceed 1.0 as the cover density is reduced. This results from increased exposure of the snowpack, resulting in increased sublimation and evaporation. Two sets of relationships were derived. Figures III.54 and III.55 should be used to modify baseline evapotranspiration of figure III.35 in high snow accumulation areas; figures III.52 and III.53 are recommended for use in areas of moderate to low snow accumulation for figure III.35.

Modifier coefficients for the New England/Lake State region (1) are presented in figure III.56.

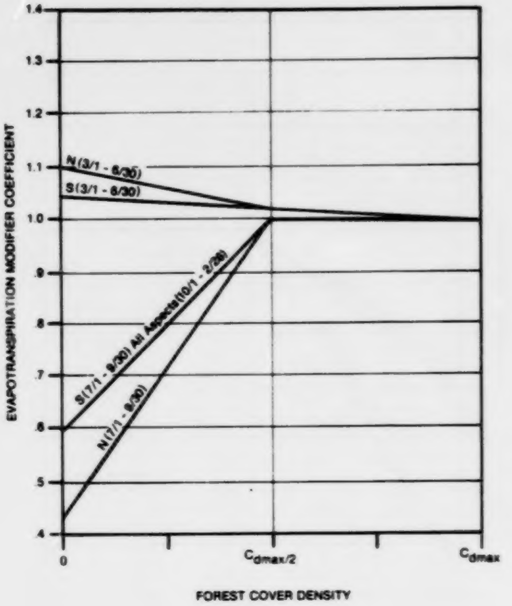


Figure III.46.—Evapotranspiration modifier coefficients for forest cover density changes for the Rocky Mountain/Inland Intermountain hydrologic region (4).

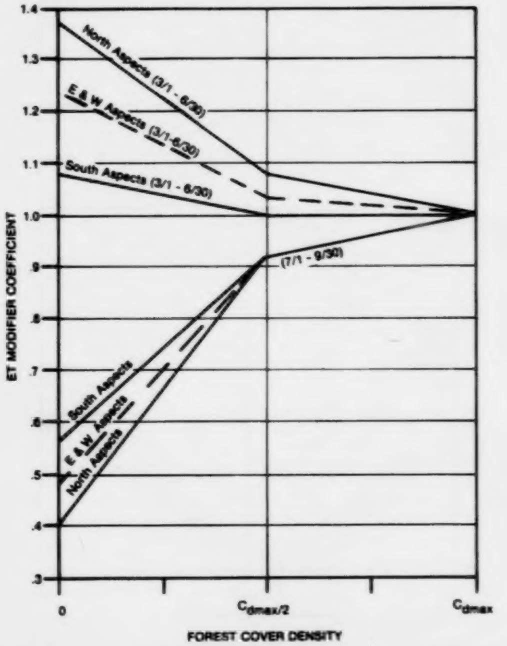


Figure III.47.—Evapotranspiration modifier coefficients for forest cover density changes for the Continental/Maritime hydrologic province (6) high and intermediate energy aspects—spring, summer and fall seasons.

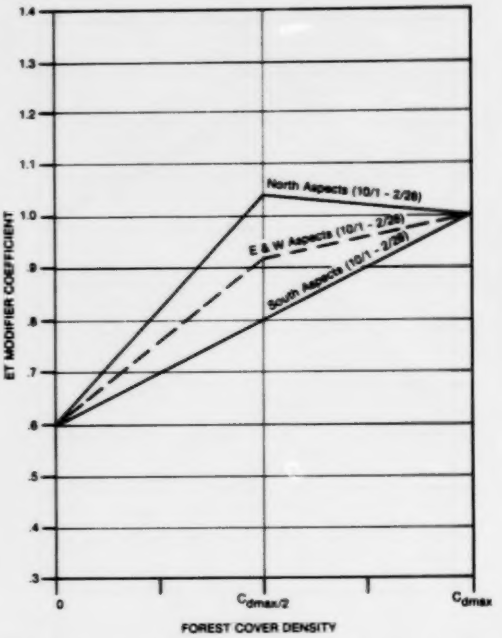


Figure III.48.—Evapotranspiration modifier coefficients for forest cover density changes for the Continental/Maritime hydrologic province (6) high and intermediate energy aspects—winter season.

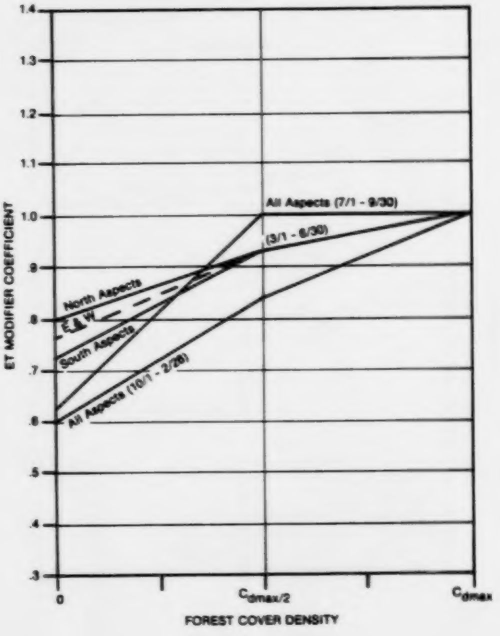


Figure III.49.—Evapotranspiration modifier coefficients for forest cover density changes for the Continental/Maritime hydrologic province (6) low energy aspects—all seasons.

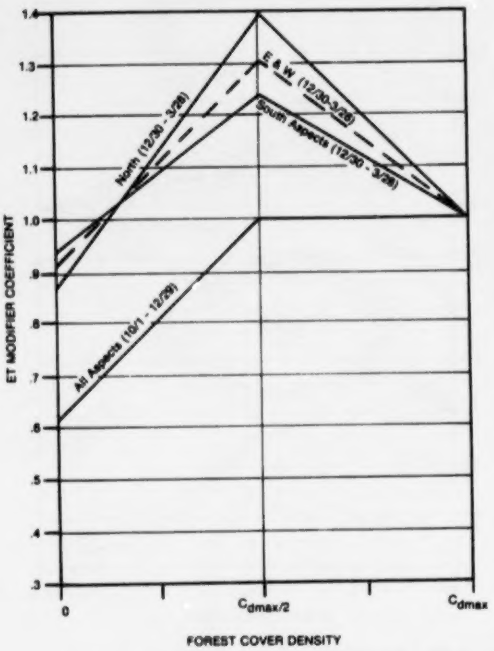


Figure III.50.—Evapotranspiration modifier coefficients for forest cover density changes for the Central Sierra hydrologic province (7) intermediate and low energy aspects—early and late winter seasons.

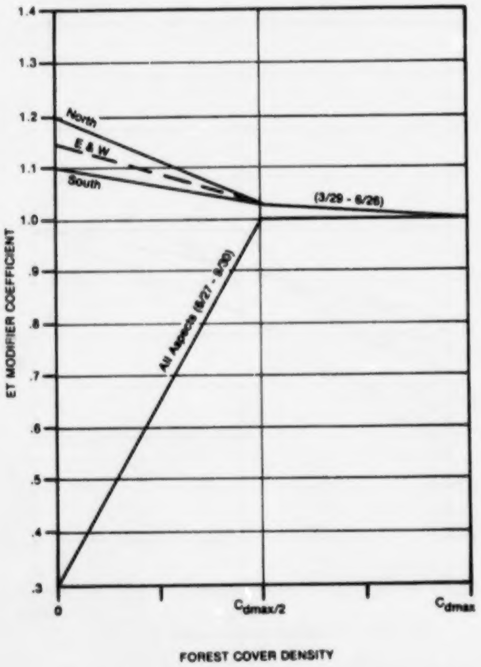


Figure III.51.—Evapotranspiration modifier coefficients for forest cover density changes for the Central Sierra hydrologic province (7) intermediate and low energy aspects—spring, summer and fall seasons.

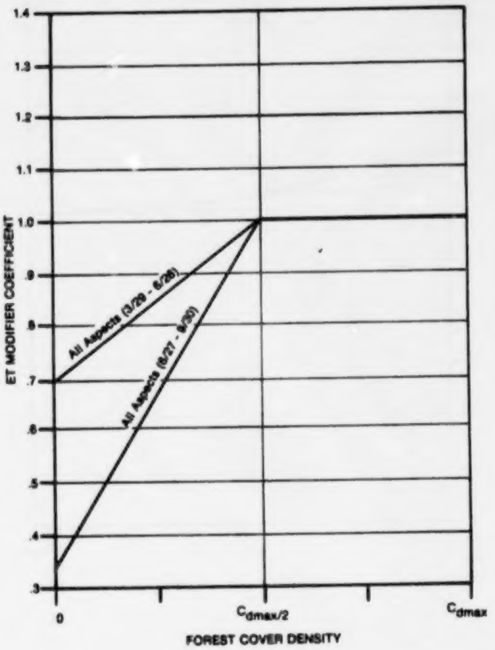


Figure III.52.—Evapotranspiration modifier coefficients for forest cover density changes for the Central Sierra hydrologic province (7) high energy aspects—spring, summer and fall seasons.

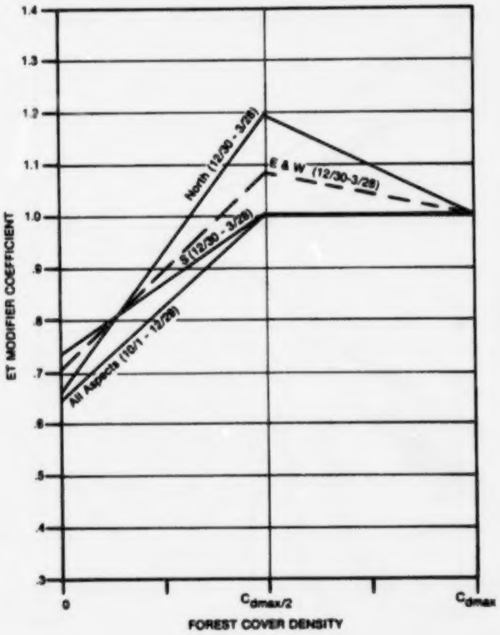


Figure III.53.—Evapotranspiration modifier coefficients for forest cover density changes for the Central Sierra hydrologic province (7) high energy aspects—early and late winter seasons.

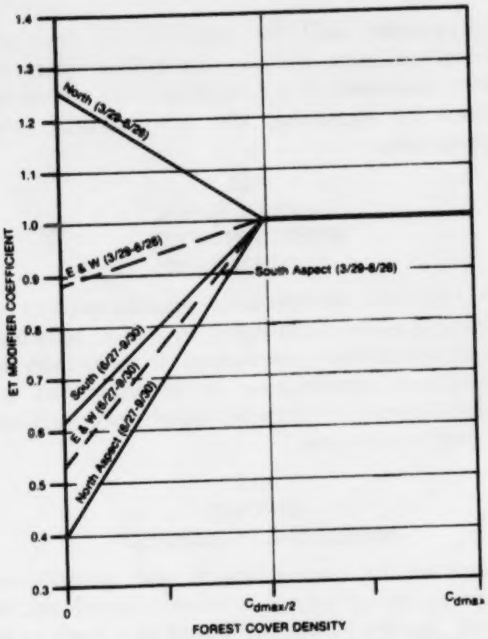


Figure III.54.—Evapotranspiration modifier coefficients for forest cover density changes for the Northwest hydrologic province (5) all energy aspects—spring, summer, and fall seasons.

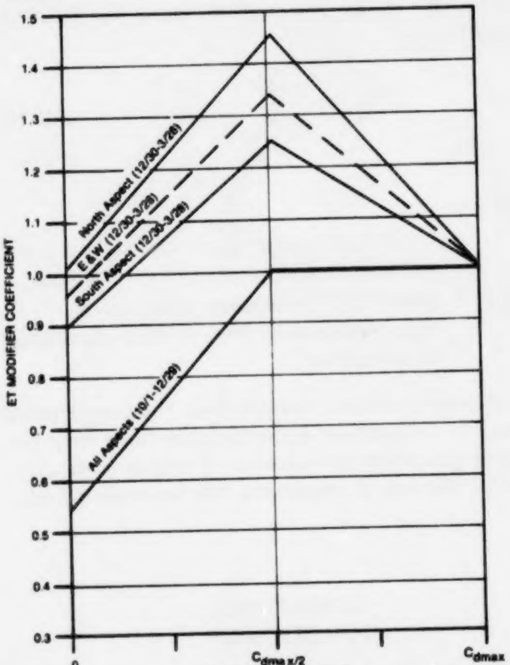


Figure III.55.—Evapotranspiration modifier coefficients for forest cover density changes for the Northwest hydrologic province (5) all energy aspects—early and late winter seasons.

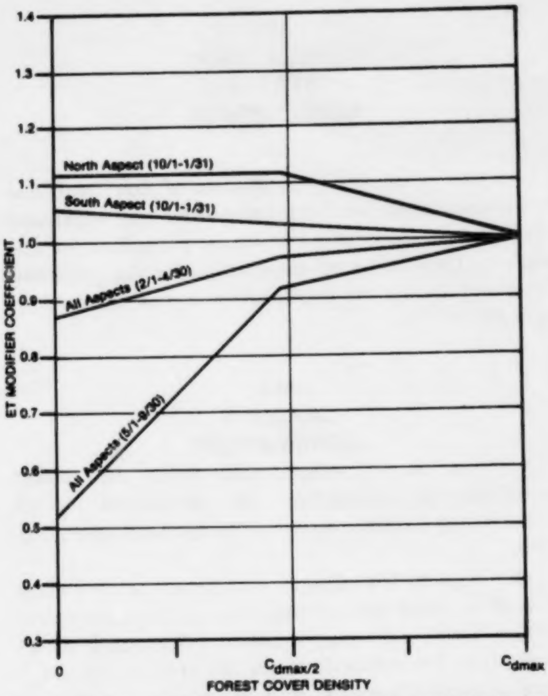


Figure III.56.—Evapotranspiration modifier coefficients for forest cover density changes for the New England/Lake States hydrologic region (1) all energy aspects—all seasons.

ADJUSTED EVAPOTRANSPIRATION

Adjusted seasonal evapotranspiration (item 23) for the silvicultural state is obtained by multiplying evapotranspiration (item 18) by its corresponding modifier coefficient (item 22).

WATER AVAILABLE FOR STREAMFLOW

Multiplication of the treatment area (as a decimal percentage of the watershed area, item 13) times the difference between adjusted precipitation and adjusted evapotranspiration (item 17-item 23) is an estimate of area weighted contribution to total watershed flow that will be derived from the treatment (or state) area by season and is entered in one of the columns from 24-29. The seasonal values for each hydrologic state should be placed in separate columns so that they can later be summed and entered in columns 30-35, appropriately.

ALL SILVICULTURAL STATES CONSIDERED?

At this point the contribution of flow from one treatment area has been calculated and expressed in inches of flow from the entire watershed for one season. Only after all treatments for the prescription and season are evaluated is a new season considered.

ALL SEASONS CONSIDERED?

Calculations of evapotranspiration and water available for streamflow are performed for all silvicultural states, seasons, within each prescription.

A return to the silvicultural prescription step of the flow chart and completion of the subsequent steps until all evapotranspiration and water available for streamflow for all treatments for a prescription by season have been calculated is required.

Once the seasonal loop has been completed, annual ET, by treatment, can be summed using the following equation:

$$ET_A = \sum_{i=1}^{n} \epsilon_i ET_i = \epsilon_1 ET_1 + \epsilon_2 ET_2 + \ldots \epsilon_n ET_n \quad \text{(III.14)}$$

where:

ET_A = annual evapotranspiration

ϵ_i = evapotranspiration modifier coefficients (by season) that vary with forest cover density (item 22)

ET_i = seasonal evapotranspiration (item 18)

n = number of seasons

WATER AVAILABLE FOR ANNUAL STREAMFLOW BY STATE

Since streamflow timing differs by silvicultural treatment, water available for streamflow for the entire year must be sorted by treatment. Water available for streamflow for each treatment is summed for each season yielding water available for annual streamflow by season and treatment (enter in col. 30-35). In the next section, hydrographs will be constructed for each silvicultural state. A composite hydrograph for the entire watershed or watershed subunit will be obtained by summing the silvicultural state hydrographs.

ALL SILVICULTURAL PRESCRIPTIONS CONSIDERED?

At this point, all calculations for the impacts of a number of silvicultural states, by season, have been completed for one prescription. If more than one silvicultural prescription is recommended per energy aspect or more energy aspects per condition, the loop is repeated.

ALL ENERGY ASPECTS CONSIDERED?

Once all the calculations for each prescription within an energy aspect have been considered, all energy aspects within each condition need to be evaluated.

To obtain an estimate of annual flow, for the condition one first has to sum the contribution from each state in the prescription using the following equation:

$$Q_P = \sum_{T=30}^{35} Q_T \quad \text{(III.15)}$$

where:

Q_P = Contribution (in area inches) to total watershed flow, from the prescription.

Q_T = Flow from treatment area (items 30-35 from worksheets III.5 or III.6 depending on condition).

To estimate total watershed flow, the prescription flows can be summed by adding the flows from the various prescriptions together. If only one prescription is defined, it represents the watershed flow.

ALL CONDITIONS CONSIDERED?

The flow chart is constructed so that water available for annual streamflow is calculated for all energy aspects for one condition before the other conditions are considered. The order in which aspects and conditions are considered may be changed to fit specific needs. Nonetheless, all conditions (proposed, existing, etc.) and all energy aspects (or watershed subunits) for the basin must be dealt with in an orderly manner before proceeding with hydrograph construction in the section, "Procedural Description: Determining Streamflow Timing and Volume Changes Associated With Silvicultural Activities."

END

At this point the user has values of water available for annual streamflow sorted by silvicultural state, prescription, and energy aspect and condition. The next step is construction of desired hydrographs for the basin of interest.

Example: Determining ET And Water Available For Annual Streamflow (Snow Dominated Regions)

The following is an example of how to use the methodology. Worksheets are not used but the methodology steps are done in order to arrive at the information needed for the worksheets. The example is Hubbard Brook (New Hampshire), watershed 3.

Step 1. Any watershed under consideration may need to be delineated and divided into subunits by aspect (item 4). Also needed in order to further subdivide the watershed into homogeneous subunits are timber stand data, including the species; basal area (item 19) or cover density (item 20); history of cutting; and the proposed silvicultural prescriptions (including the nature of the cut and the size and spacing of openings if they will be created).

Hubbard Brook watershed can be treated as having one energy aspect with a southerly exposure. The pre-silvicultural condition is fully forested ($C_d = C_{dmax}$) and the example silvicultural prescription is a reduction to $C_d = 0$ (completely clearcut).

Step 2. Determine the average annual and seasonal precipitation (item 14) that can be expected for the design year. This can be obtained locally from published data, or from a precipitation/elevation curve developed for the area.

For Hubbard Brook the precipitation is 47.6 inches per year, with 12.1 inches occurring between October 1 and January 31, 13.0 inches occurring between February 1 and April 30, and 22.5 inches occurring between May 1 and September 30.

Given the information available to this point, it is possible to estimate the potential baseline evapotranspiration (item 18) which might occur on the site in the following manner, using figure III.38 (south aspect).

Season (item 9)	Precipitation (item 14)	Baseline ET (item 18)
10/1-1/31	12.1	2.45
2/1-4/30	13.0	2.65
5/1-9/30	22.5	16.70
Total	47.6	21.80

Of the 47.6 inches of precipitation, approximately 21.8 inches will be used for evapotranspiration and 25.8 inches is water potentially available for streamflow (item 30).

Step 3. After establishing baseline conditions, changes due to the proposed silvicultural prescription are determined. In this example, prescription and state are one. First, evaluate the pattern and nature of the cut; use the procedures given to adjust the precipitation input to reflect snow redistribution if it can be expected to occur.

For Hubbard Brook, no adjustment is made for redistribution. The comprehensive example presented for the Rocky Mountain/Inland Intermountain hydrologic region (4) presented subsequently in this handbook will illustrate the procedure that should be used to quantify the impacts of silvicultural activities on snow accumulation and redistribution.

Step 4. When precipitation has been adjusted to account for the proposed treatment, evapotranspiration must be adjusted to reflect the expected change. This is done in the following manner using input data above and figure III.56 (assume $C_d = 0$ after harvest, $C_d = C_{dmax}$ before harvest).

Season (item 9)	Precipitation (item 14) (given)	Baseline ET (item 18) (fig. III.38)	ET Modifier (item 22) (fig. III.56)	Post-activity evapotranspiration
10/1-1/31	12.1	2.45	1.06	2.60
2/1-4/30	13.0	2.65	.88	2.33
5/1-9/30	22.5	16.7	.52	8.68
Total	47.6	21.8	---	13.61

The expected post-activity evapotranspiration is 13.6 inches and the water available for streamflow is 34.0 inches (47.6-13.6). The expected increase in flow, due to an evapotranspiration reduction, is 8.2 inches. The observed change in flow (Hornbeck and Federer 1975) averaged about 11.5 inches.

In the above example no adjustments were made for snow redistribution. This, in turn, would adjust post-silvicultural activity evapotranspiration rates because precipitation would have been altered. Also the basin silvicultural activity was not complicated because the entire basin was treated uniformly in pre- and post-silvicultural activity conditions. There was no need to adjust the response for differing practices and aspects on the same watershed. This will be covered in the complete example for Horse Creek (ch. VIII). The methodology presented in steps 1-4 is used to evaluate, for any silvicultural activity, the water potentially made available by the evapotranspiration reduction. This water is then routed to the soil moisture and streamflow components of the analysis (see next section).

PROCEDURAL DESCRIPTION: DETERMINING POTENTIAL CHANGES IN STREAMFLOW (STREAMFLOW ESTIMATION) (SNOW DOMINATED REGIONS)

NEW ENGLAND/LAKE STATES (REGION 1)
ROCKY MOUNTAIN/INLAND INTERMOUNTAIN (REGION 4)
PACIFIC COAST REGION, HIGHER ELEVATION ZONES (PROVINCES 5, 6, 7)

Unlike the rain dominant regions, the hydrologic regime in snow dominated regions allows water potentially available for flow to be distributed in a time dependent hydrograph or distribution graph. In the snow dominated regions, a significant portion of the annual flow does occur in a predictable manner as the result of melting snow.

A significant impact on the hydrology of these areas is modification of the rate of snowmelt through forest manipulation which not only alters the quantity of water, but the peak flow rates and timing as well (Anderson and others 1976, Swanson and others 1977). Therefore, in order to provide a useful tool in evaluating the impacts of silvicultural activities, it is necessary to provide a means of distributing changes in potential flow and a means for evaluating when changes would occur.

Of the two hydrologic regions (1 and 4) and three hydrologic provinces (5, 6, and 7) that are snow dominated, one is considered an exception. The New England/Lake States hydrologic region (1), because of its winter snowpack, had to be included in this group for modeling purposes. However, the snowpack development in this region does not truly dominate the hydrograph. The rainfall generated portion of the hydrograph is also quite significant. For this reason, the techniques for presenting the effect of silvicultural activities on the water potentially available for flow will be dealt with separately at the end of this section in a manner more closely related to rain dominated techniques.

PROCEDURAL FLOW CHART

The flow chart outlining the procedure for streamflow estimation is given in figure III.57 and discussed below. Worksheets III.7 and III.8 have been constructed to facilitate calculations.

HYDROLOGIC REGION OR PROVINCE

Define the hydrologic region characteristics of the site. (This has already been done for the ET estimation.)

HYDROLOGIC REGION 1?

Since snow does not dominate the hydrology of the New England/Lake States region (1) to the extent it does in hydrologic region 4 and provinces 5, 6, and 7, streamflow procedures are different for hydrologic region 1. For this region, flow duration curves instead of hydrographs are developed. For the rest of the flow chart for Region 1, review "New England/Lake States (Region 1)" which is discussed later in this section. For Region 4, and the Pacific Coast hydrologic provinces 5, 6, and 7, continue with the procedure described immediately below.

CONDITION

As with the ET calculations, perform the analysis on each watershed condition.

ENERGY ASPECT

Watershed subdivision into energy aspect units is the same as for the ET calculations.

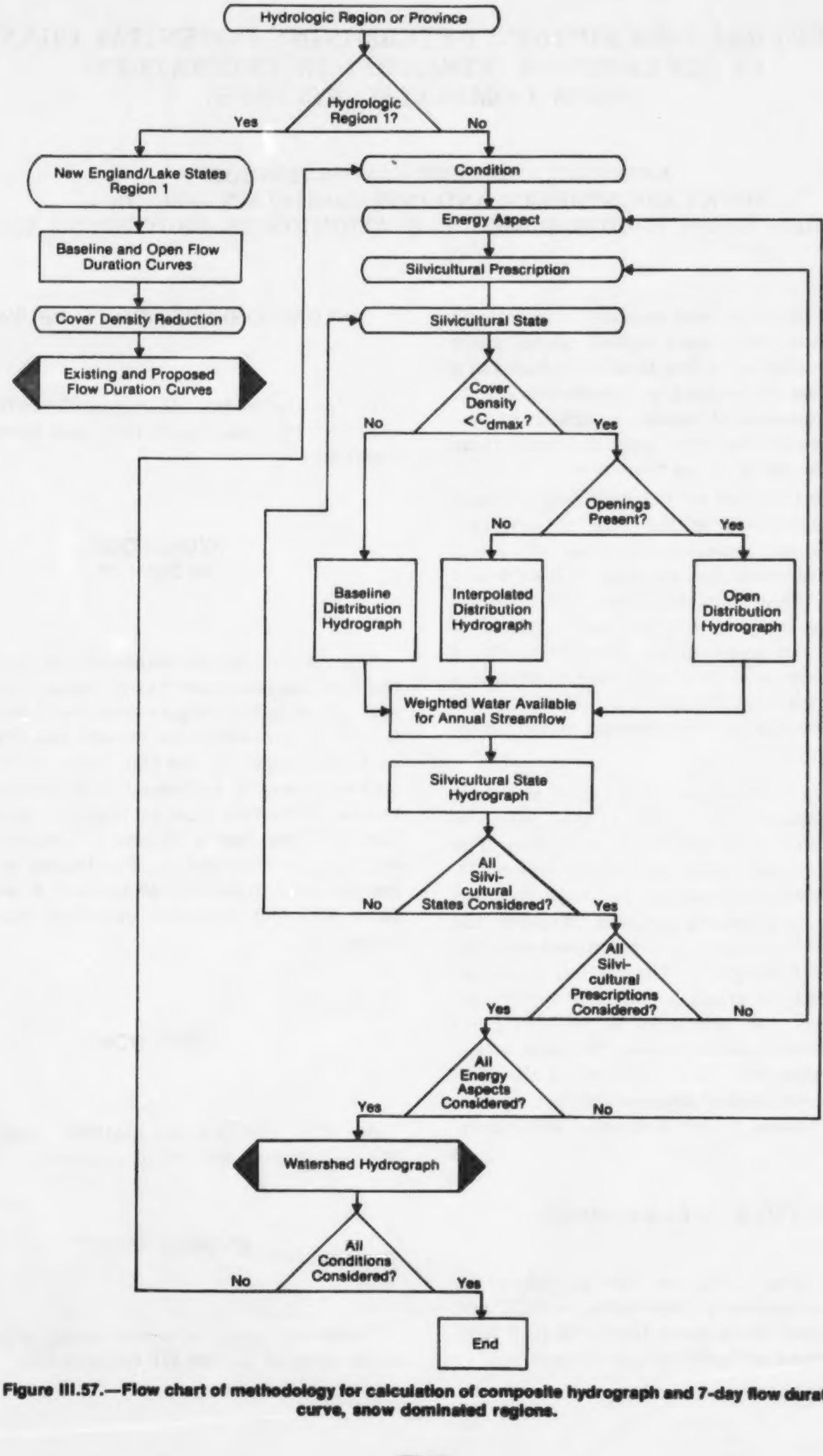

Hydrologic Region or Province
Hydrologic Region 1?
Yes
No
New England/Lake States Region 1
Baseline and Open Flow Duration Curves
Cover Density Reduction
Existing and Proposed Flow Duration Curves
Condition
Energy Aspect
Silvicultural Prescription
Silvicultural State
Cover Density <C dmax?
No
Yes
Openings Present?
No
Yes
Baseline Distribution Hydrograph
Interpolated Distribution Hydrograph
Open Distribution Hydrograph
Weighted Water Available for Annual Streamflow
Silvicultural State Hydrograph
All Silvi-cultural States Considered?
No
Yes
All Silvi-cultural Prescriptions Considered?
Yes
No
All Energy Aspects Considered?
Yes
No
Watershed Hydrograph
All Conditions Considered?
No
Yes
End

Figure III.57.—Flow chart of methodology for calculation of composite hydrograph and 7-day flow duration curve, snow dominated regions.

SILVICULTURAL PRESCRIPTION

As with the ET calculations, the silvicultural prescription for each energy aspect must be defined. Each prescription can include one or more silvicultural states or treatments.

SILVICULTURAL STATE

As defined, silvicultural state relates to the actual treatment or activity to be employed (i.e., thinning, clearing, etc.) or describes the vegetative state in the absence of management.

The above items (condition, energy aspect, silvicultural prescription, and silvicultural state) define the watershed divisions which are used as components to each analytical loop.

COVER
DENSITY
$<C_{dmax}$?

Silvicultural activities are matched to normalized distribution graphs according to cover density (C_d) for the activity. Guidelines for estimating maximum cover density (C_{dmax}) as well as cover densities for other states have been outlined in the previous section on evapotranspiration for snow dominated regions.

If the site is at a baseline condition then a baseline hydrograph is determined. If cover density for the site (treatment area) is less than maximum either for the existing condition or for proposed conditions the presence of openings must first be determined and then the appropriate distribution graph must be constructed.

Two forms of the distribution graph will be presented. The first represents average regional distribution of annual flow for baseline conditions. The other represents regional distribution of annual flow for open conditions. Intermediate silvicultural states are obtained by interpolation. A discussion of each follows.

In the Rocky Mountain/Inland Intermountain hydrologic region (4), the onset of the runoff excess distribution varies throughout the region given the constraints under which the methodology was developed. Accordingly, the appropriate date of the onset of spring melt must be known for a given watershed. This date must be supplied for the planning unit. However, it is assumed that the relative timing of flows from the various energy aspects is uniform throughout the hydrologic region.

The simulated distribution graphs for each of the three energy aspects are presented in figure III.58. The curves represent the average baseline distribution graphs from the simulation of hundreds of station years of record. Simulations were also made which reduced the baseline cover density by 50 and 100 percent. As has been noted, reduction of cover density by 50 percent resulted in little, if any, simulated change in either potential streamflow or its distribution.

Figures III.59 to III.61 present comparisons between the potential flow distribution graphs for forest and open conditions for the three energy aspects. In figures III.59 to III.61 the x, or time axis, is not specifically dated, although it has been plotted on a continuous 6-day interval. The date on which the peak flow will occur under baseline conditions must be estimated before the rest of the graph can be dated accordingly. The simulated shift in peak on specific aspects due to forest removal can be up to 6 weeks sooner and approximately 3 percent higher.

These figures (III.59 to III.61) represent the normalized distributions of the percentage of the total annual flow (either baseline or open) which can be expected to occur during any 6-day period throughout the year. To simplify adjusting the baseline condition for the proposed silvicultural activity, the percentages for each 6-day interval have been tabulated by energy level in tables III.11 to III.13. These tables represent the digitized potential streamflow distribution for both open and forested areas by energy aspect.

Use of the distribution graphs and tables for adjusting potential flow will be explained after similar data for the other snow dominated regions and provinces has been presented.

The Pacific Northwest region consists of three provinces: The Continental/Maritime (6), the Central Sierra (7), and the Northwest (5). Following is a discussion of each.

WORKSHEET

Existing condition hydrograph

(1) Watershed name ____________________

Date or interval (3)	Distribution of water								
	Unimpacted						Impacted		
	% (4)	inches (5)	cfs (6)	% (7)	inches (8)	cfs (9)	% (10)	inches (11)	cfs (12)

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in text.
(3)	Supplied by user. Either date snowmelt begins or date of peak snowmelt runoff.
(4),(7), (10),(13), (16),(19)	Digitized excess water distribution (%) from tables III.11 to III.22 for forested and open condition. Interpolate between forested and open for other conditions.

III.7

for snow dominated regions

(2) Hydrologic region ________________

available for annual streamflow									Composite hydrograph
Impacted (continued)									
% (13)	Inches (14)	cfs (15)	% (16)	Inches (17)	cfs (18)	% (19)	Inches (20)	cfs (21)	cfs (22)

(5),(8), (11),(14), (17),(20)	Digitized excess water distribution (%) multiplied by water available for annual streamflow gives flow in inches.
(6),(9), (12),(15), (18),(21)	To convert from area inches to cfs, the area-inch hydrograph is multiplied by:

$$\frac{\text{Total watershed area (in acres)}}{\text{(12 in/ft) (1.98) (Number of days in interval)}}$$

(22)	Sum of columns (6), (9), (12), (15), (18), and (21) gives the composite hydrograph for the entire watershed in cfs.

WORKSHEET

Proposed condition hydrograph

(1) Watershed name ____________________

Date or Interval (3)	Distribution of water								
	Unimpacted						Impacted		
	% (4)	Inches (5)	cfs (6)	% (7)	Inches (8)	cfs (9)	% (10)	Inches (11)	cfs (12)

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in text.
(3)	Supplied by user. Either date snowmelt begins or date of peak snowmelt runoff.
(4),(7), (10),(13), (16),(19)	Digitized excess water distribution (%) from tables III.11 to III.22 for forested and open condition. Interpolate between forested and open for other conditions.

III.8

for snow dominated regions

(2) Hydrologic region ____________________

available for annual streamflow									
Impacted (continued)									Composite hydrograph
% (13)	Inches (14)	cfs (15)	% (16)	Inches (17)	cfs (18)	% (19)	Inches (20)	cfs (21)	cfs (22)

(5),(8), (11),(14), (17),(20)	Digitized excess water distribution (%) multiplied by water available for annual streamflow gives flow in inches.
(6),(9), (12),(15), (18),(21)	To convert from area inches to cfs, the area-inch hydrograph is multiplied by:

$$\frac{\text{Total watershed area (in acres)}}{\text{(12 in/ft) (1.98) (Number of days in interval)}}$$

(22)	Sum of columns (6), (9), (12), (15), (18), and (21) gives the composite hydrograph for the entire watershed in cfs.

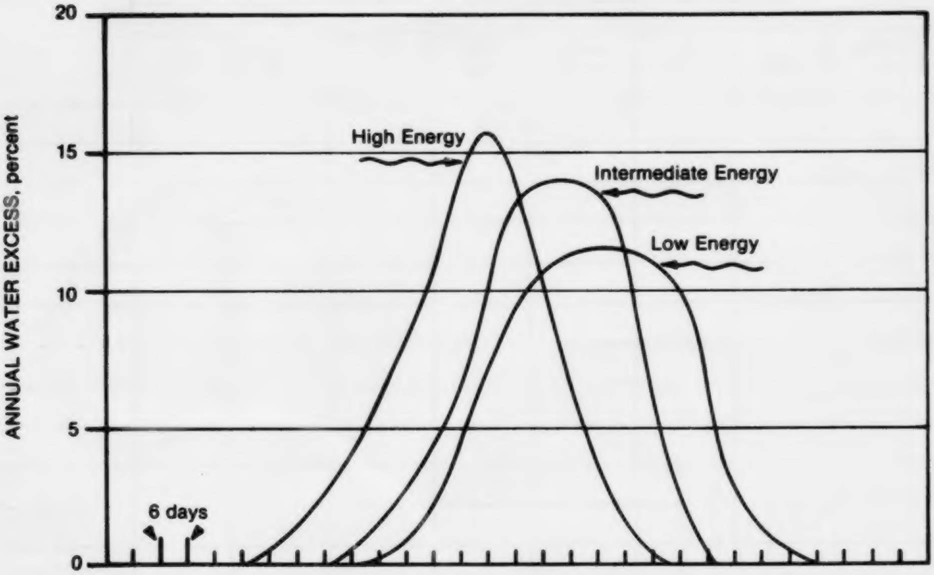


Figure III.58.—Potential water excess distribution graphs for Rocky Mountain/Inland Intermountain hydrologic region (4)—baseline conditions, all energy aspects.

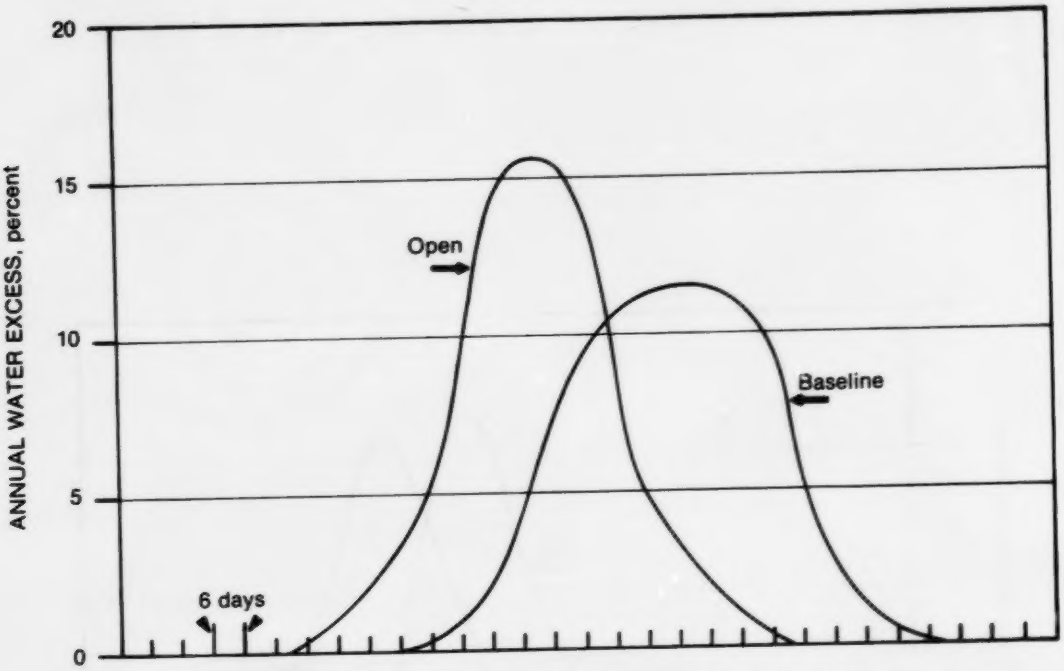


Figure III.59.—Potential water excess distribution graphs for Rocky Mountain/Inland Intermountain hydrologic region (4)—treated conditions, low energy aspects.

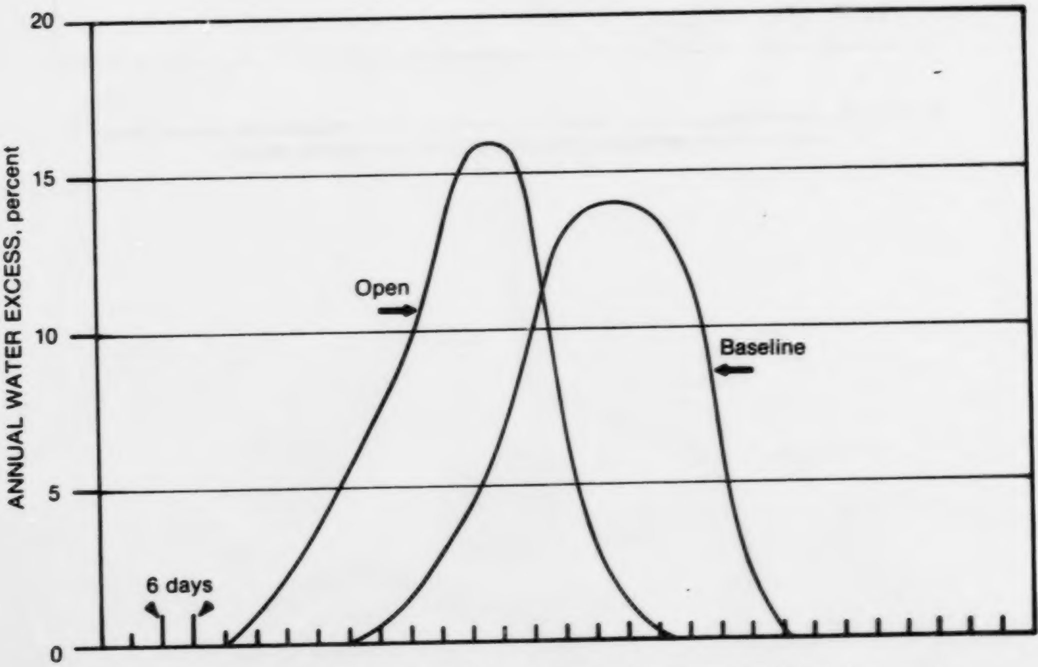


Figure III.60.—Potential water excess distribution graphs for Rocky Mountain/Inland Intermountain hydrologic region (4)—treated conditions, intermediate energy aspects.

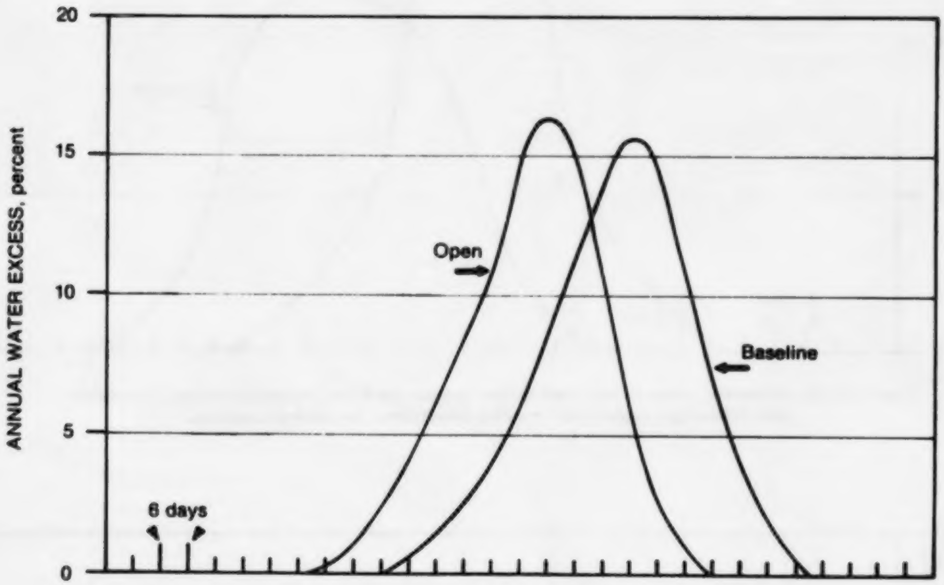


Figure III.61.—Potential water excess distribution graphs for Rocky Mountain/Inland Intermountain hydrologic region (4)—treated conditions, high energy aspects.

Table III.11.—Digitized excess water distribution for the Rocky Mountain/Inland Intermountain hydrologic region (4)—low energy aspect.

Percentage in decimals of total annual flow which will occur during 6-day flow intervals

6th day interval[1]	Full Forest	Open (Clearcut)
1	0.00	0.00
2	0.00	0.00
3	0.00	0.00
4	0.00	0.0025
5	0.00	0.0100
6	0.00	0.0200
7	0.00	0.0325
8	0.0025	0.0525
9	0.0100	0.0950
10	0.200	.01425
11	0.0475	0.1550
12	0.0725	0.1550
13	0.0925	0.1400
14	0.1050	0.0800
15	0.1125	0.0500
16	0.1150	0.0325
17	0.1150	0.0200
18	0.1125	0.0100
19	0.0975	0.0025
20	0.0550	0.00
21	0.0250	0.00
22	0.0125	0.00
23	0.0050	0.00
24	0.00	0.00
25	0.00	0.00
26	0.00	0.00
27	0.00	0.00
28	0.00	0.00
29	0.00	0.00
30	0.00	0.00

[1] The intervals are fixed in time with respect to date of peak flow. The peak data is user specified.

Table III.12.—Digitized excess water distribution for the Rocky Mountain/Inland Intermountain hydrologic region (4)—intermediate energy aspect.

Percentage in decimals of total annual flow which will occur during 6-day flow intervals

6th day interval[1]	Full Forest	Open (Clearcut)
1	0.00	0.00
2	0.00	0.00
3	0.00	0.0075
4	0.00	0.0200
5	0.00	0.0350
6	0.00	0.0550
7	0.0050	0.0750
8	0.0150	0.0950
9	0.0300	0.1350
10	0.0450	0.1550
11	0.0650	0.1600
12	0.1000	0.1300
13	0.1300	0.0825
14	0.1375	0.0325
15	0.1400	0.0125
16	0.1350	0.0050
17	0.1150	0.00
18	0.0600	0.00
19	0.0200	0.00
20	0.0025	0.00
21	0.00	0.00
22	0.00	0.00
23	0.00	0.00
24	0.00	0.00
25	0.00	0.00
26	0.00	0.00
27	0.00	0.00
28	0.00	0.00
29	0.00	0.00
30	0.00	0.00

[1] The intervals are fixed in time with respect to date of peak flow. The peak flow is user specified.

Continental/Maritime hydrologic province (6): The baseline distribution graphs for the three energy aspects within the province are plotted on figure III.62. These represent the normalized average from simulating many station years of record. The same number of simulations were made reducing the baseline cover density by 50 percent and then by 100 percent. Again, reduction by 50 percent had little, if any, effect on changing potential streamflow.

The relationships between potential flows for fully forested and open conditions are presented in figures III.63 to III.65 for each of the energy aspects. Because of the relative consistency of the simulated responses, the x or time axis has been dated. Again, a timing shift of up to 6 weeks and a change in peak flow rate can be noted.

The digitized excess water distributions represented by figures III.63 to III.65 are presented in tables III.14 to III.16 for each of the energy aspects.

Central Sierras hydrologic province (7): Simulations at a 50-percent reduction in the baseline cover density did not indicate a significant change in flow. Baseline distribution graphs of potential flow for the three energy aspects are presented in figure III.66. There are two peaks on low and intermediate energy aspects. The potential flow distributions for forested and open conditions are plotted by energy aspects on figures III.67 to III.69. Timing of peak flow rate changed by as much as 6 weeks and the rate itself by 3 percent.

Table III.13.—Digitized excess water distribution for the Rocky Mountain/Inland Intermountain hydrologic region (4)—high energy aspect.

Percentage in decimals of total annual flow which will occur during 6-day flow intervals

6th day Interval[1]	Full Forest	Open (Clearcut)
1	0.00	0.0025
2	0.00	0.0075
3	0.00	0.0250
4	0.0050	0.0425
5	0.0150	0.0650
6	0.0250	0.0825
7	0.0400	0.1075
8	0.0600	0.1475
9	0.0825	0.1650
10	0.1050	0.1450
11	0.1400	0.1150
12	0.1575	0.0625
13	0.1400	0.0250
14	0.1050	0.0075
15	0.0650	0.00
16	0.0375	0.00
17	0.0175	0.00
18	0.0050	0.00
19	0.00	0.00
20	0.00	0.00
21	0.00	0.00
22	0.00	0.00
23	0.00	0.00
24	0.00	0.00
25	0.00	0.00
26	0.00	0.00
27	0.00	0.00
28	0.00	0.00
29	0.00	0.00
30	0.00	0.00

[1] The intervals are fixed in time with respect to date of peak flow. The peak data is user specified.

The digitized excess water distributions for baseline and open conditions by energy aspects are presented in tables III.17 to III.19.

Northwest hydrologic province (5): Distribution graphs of excess water potentially available for flow simulated for the Northwest hydrologic province (5) are presented in figure III.70 for the three energy levels. The distribution graph for this province is complex with several rainfall generated peaks. The effect of simulating a 50-percent reduction in cover density was negligible. The fully forested and completely open simulations are plotted on figures III.71 to III.73. Note the slight shift in the snowmelt peak for the intermediate and low energy zones (figs. III.72 and III.73).

Digitized excess water distributions are presented in tables III.20 to III.22.

Excess water distribution values presented for both the Northwest hydrologic province (5) and Rocky Mountain/Inland Intermountain hydrologic region (4) should be properly interpreted; they have limitations. They are simulated distributions and all the errors inherent in simulation apply (see app. III.C for a detailed discussion). Because of the predictability of the snowmelt generated portion of the hydrograph, this portion of the distribution table is most representative of what may be expected and when.

The rainfall generated portions of the distribution table are more speculative. Because of the variability of rainfall patterns, these portions of the hydrograph can be normalized only to the extent

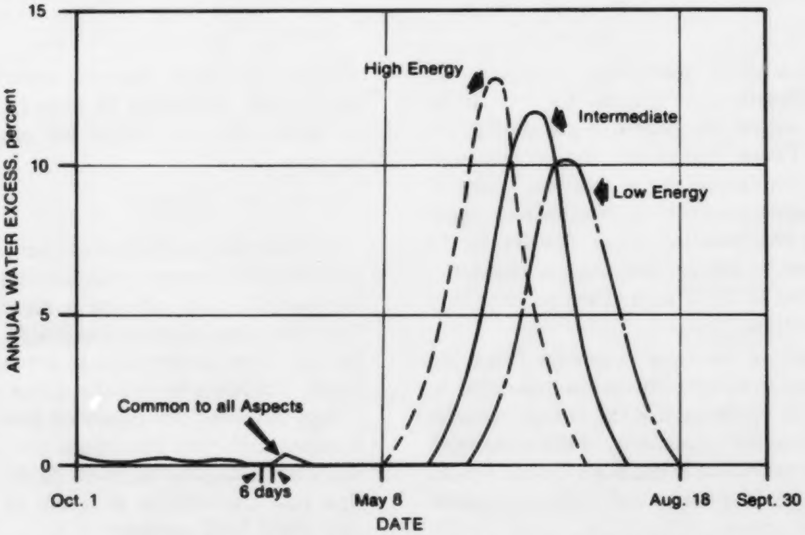


Figure III.62.—Potential water excess distribution graphs for Continental/Maritime hydrologic region (6)— baseline conditions, all energy aspects.

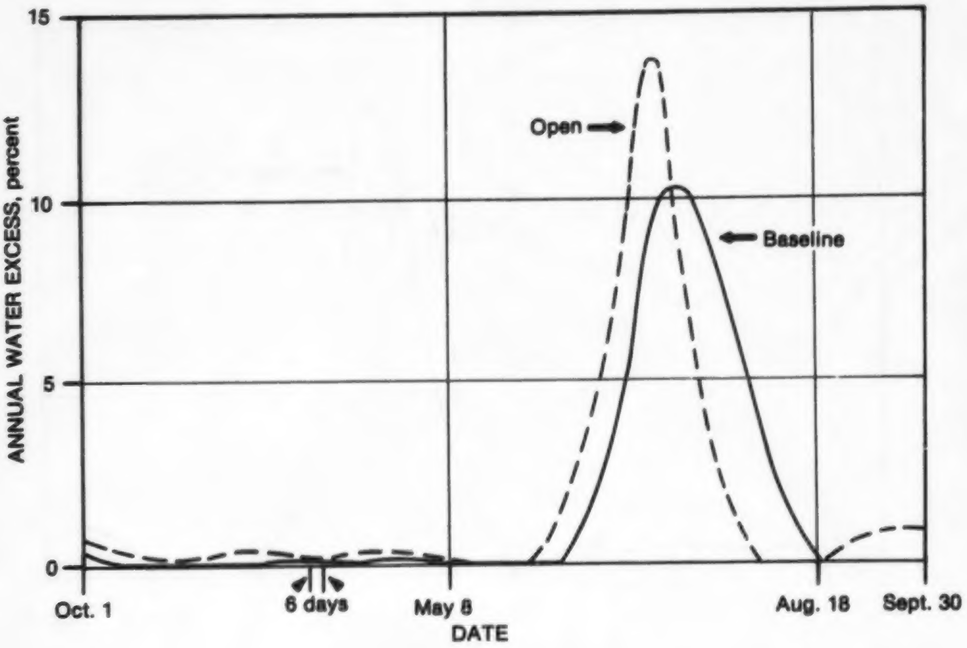


Figure III.63.—Potential water excess distribution graphs for Continental/Maritime hydrologic region (6)—treated conditions, low energy aspects.

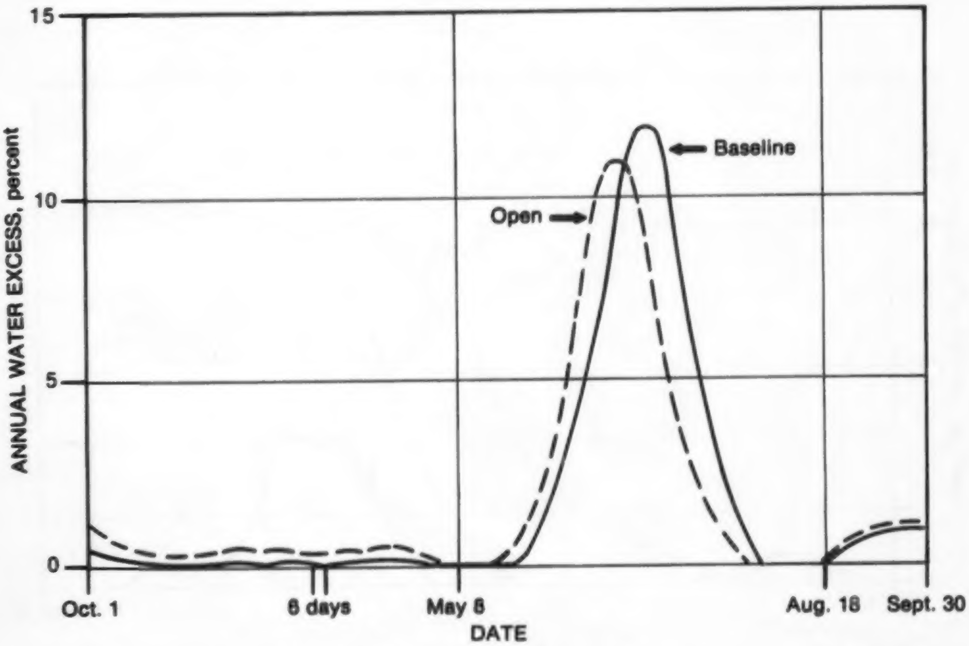


Figure III.64.—Potential water excess distribution graphs for Continental/Maritime hydrologic region (6)—treated conditions, intermediate energy aspects.

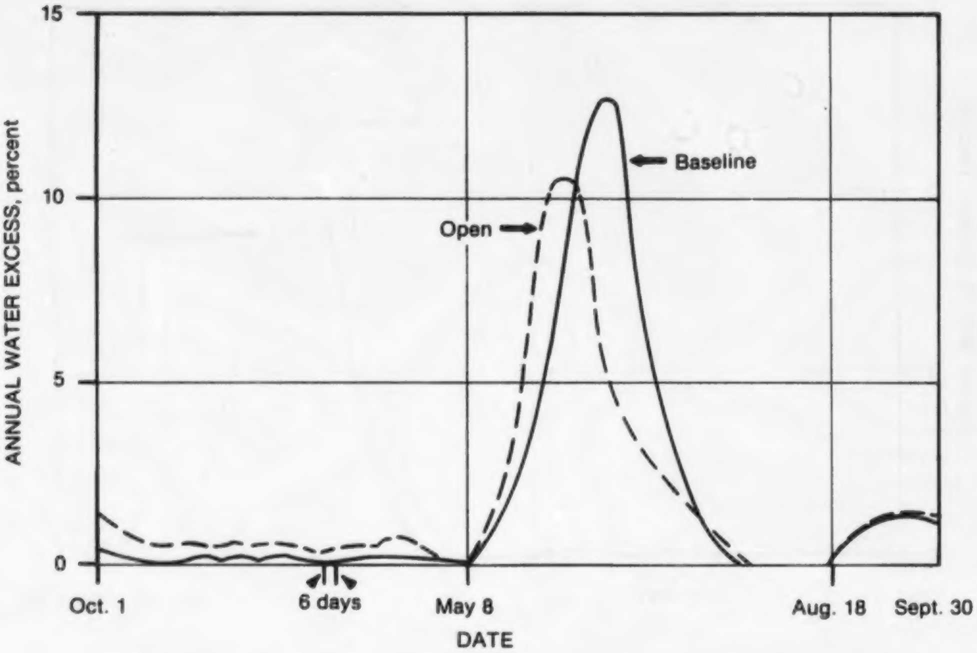


Figure III.65.—Potential water excess distribution graph for Continental/Maritime hydrologic region (6)—treated conditions, high energy aspects.

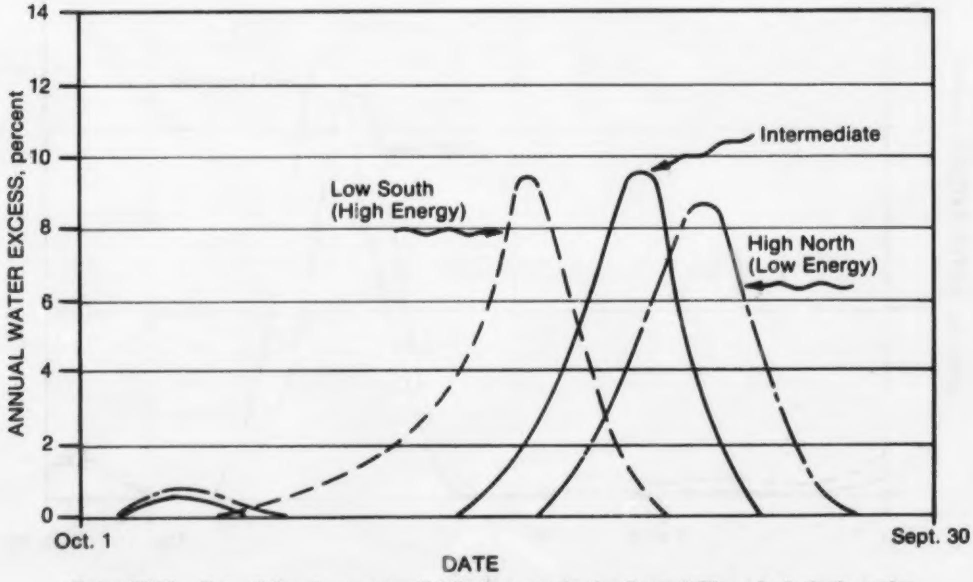


Figure III.66.—Potential water excess distribution graphs for Central Sierra hydrologic region (7)—baseline conditions, all energy aspects.

Table III.14.—Digitized excess water distribution for the Continental/Maritime hydrologic province (6)—low energy aspects.

Percentage in decimals of total annual flow which will occur during 6-day flow intervals

Block	6th day interval	Full Forest	Open (Clearcut)
Oct. 1	1	0.0028	0.0076
	2	0.0018	0.0047
	3	0.0014	0.0036
	4	0.0012	0.0031
	5	0.0007	0.0018
	6	0.0004	0.0010
	7	0.0006	0.0015
	8	0.0010	0.0026
	9	0.0004	0.0010
	10	0.0008	0.0021
	11	0.0012	0.0031
	12	0.0010	0.0026
	13	0.0008	0.0021
	14	0.0010	0.0026
	15	0.0012	0.0031
	16	0.0010	0.0026
	17	0.0008	0.0021
	18	0.0004	0.0010
	19	0.0006	0.0015
	20	0.0003	0.0008
	21	0.0012	0.0031
	22	0.0014	0.0036
	23	0.0016	0.0042
	24	0.0010	0.0026
	25	0.0004	0.0010
Feb. 28	26	0.00	0.00
	27	0.00	0.00
	28	0.00	0.00
	29	0.00	0.00
	30	0.00	0.00
	31	0.00	0.00
Apr. 11	32	0.00	0.0004
	33	0.00	0.0053
Apr. 23	34	0.0008	0.0125
	35	0.0061	0.0230
	36	0.0154	0.0356
	37	0.0267	0.0479
	38	0.0395	0.0645
	39	0.0541	0.0869
	40	0.0710	0.1093
	41	0.0922	0.1366
	42	0.0995	0.1237
	43	0.1019	0.0946
	44	0.0995	0.0634
	45	0.0922	0.0440
	46	0.0794	0.0212
	47	0.0669	0.0133
	48	0.0529	0.0069
Jul. 18	49	0.0352	0.0012
	50	0.0219	0.00
	51	0.0133	0.00
	52	0.0061	0.00
Aug. 12	53	0.0004	0.00
Aug. 18	54	0.00	0.0006
	55	0.00	0.0026
	56	0.00	0.0047
	57	0.00	0.0063
	58	0.00	0.0070
	59	0.00	0.0074
	60	0.00	0.0079
Sept. 30	61	0.00	0.0082

Table III.15.—Digitized excess water distribution for the Continental/Maritime hydrologic province (6)—intermediate energy aspects.

Percentage in decimals of total annual flow which will occur during 6-day flow intervals

Block	6th day interval	Full Forest	Open (Clearcut)
Oct. 1	1	0.0028	0.0106
	2	0.0018	0.0068
	3	0.0014	0.0053
	4	0.0012	0.0046
	5	0.0007	0.0027
	6	0.0004	0.0015
	7	0.0006	0.0023
	8	0.0010	0.0038
	9	0.0004	0.0015
	10	0.0008	0.0030
	11	0.0012	0.0046
	12	0.0010	0.0038
	13	0.0008	0.0030
	14	0.0010	0.0038
	15	0.0012	0.0046
	16	0.0010	0.0038
	17	0.0008	0.0030
	18	0.0004	0.0015
	19	0.0006	0.0023
	20	0.0003	0.0011
	21	0.0012	0.0046
	22	0.0014	0.0053
	23	0.0016	0.0061
	24	0.0010	0.0039
	25	0.0004	0.0015
Feb. 28	26	0.00	0.00
	27	0.00	0.00
	28	0.00	0.00
Mar. 24	29	0.00	0.0008
	30	0.00	0.0036
Apr. 5	31	0.0008	0.0077
	32	0.0080	0.0164
	33	0.0184	0.0284
	34	0.0288	0.0421
	35	0.0437	0.0605
	36	0.0581	0.0838
	37	0.0706	0.1014
	38	0.0926	0.1091
	39	0.1115	0.1070
	40	0.1183	0.0954
	41	0.1183	0.0694
	42	0.1014	0.0493
	43	0.0733	0.0344
	44	0.0542	0.0213
	45	0.0372	0.0125
	46	0.0221	0.0053
	47	0.0120	0.0016
	48	0.0053	0.00
Jul. 18	49	0.0004	0.00
	50	0.00	0.00
	51	0.00	0.00
	52	0.00	0.00
	53	0.00	0.00
	54	0.00	0.0005
	55	0.00	0.0030
	56	0.00	0.0050
	57	0.00	0.0070
	58	0.00	0.0086
	59	0.00	0.0096
	60	0.00	0.0104
Sept. 30	61	0.00	0.0109

Table III.16.—Digitized excess water distribution for the Continental/Maritime hydrologic province (6)—high energy aspects.

Percentage in decimals of total annual flow which will occur during 6-day flow intervals

Block	6th day interval	Full Forest	Open (Clearcut)
Oct. 1	1	0.0028	0.0140
	2	0.0018	0.0090
	3	0.0014	0.0070
	4	0.0012	0.0060
	5	0.0007	0.0035
	6	0.0004	0.0020
	7	0.0006	0.0030
	8	0.0010	0.0050
	9	0.0004	0.0020
	10	0.0008	0.0040
	11	0.0012	0.0060
	12	0.0010	0.0050
	13	0.0008	0.0040
	14	0.0010	0.0050
	15	0.0012	0.0060
	16	0.0010	0.0050
	17	0.0008	0.0040
	18	0.0004	0.0020
	19	0.0006	0.0030
	20	0.0003	0.0015
	21	0.0012	0.0060
	22	0.0014	0.0070
	23	0.0016	0.0080
	24	0.0010	0.0050
	25	0.0004	0.0020
Mar. 12	26	0.00	0.00
	27	0.0004	0.0004
	28	0.0061	0.0062
	29	0.0121	0.0175
	30	0.0194	0.0312
	31	0.0312	0.0578
	32	0.0497	0.0887
	33	0.0783	0.1058
	34	0.0892	0.1074
	35	0.1105	0.1016
	36	0.1247	0.0672
	37	0.1255	0.0494
	38	0.1134	0.0385
	39	0.0722	0.0333
Jul. 12	40	0.0521	0.0286
	41	0.0331	0.0229
	42	0.0223	0.0187
	43	0.0158	0.0154
	44	0.0101	0.0104
	45	0.0061	0.0062
	46	0.0024	0.0024
	47	0.0004	0.0004
	48	0.00	0.00
	49	0.00	0.00
	50	0.00	0.00
	51	0.00	0.00
	52	0.00	0.00
	53	0.00	0.00
Aug. 18	54	0.00	0.0004
	55	0.00	0.0020
	56	0.00	0.0061
	57	0.00	0.0085
	58	0.00	0.0101
	59	0.00	0.0114
	60	0.00	0.0127
Sept. 30	61	0.00	0.0138

Table III.17.—Digitized excess water distribution for the Central Sierra hydrologic province (7)—low energy aspects.

Percentage in decimals of total annual flow which will occur during 6-day flow intervals

Block	6th day interval	Full Forest	Open (Clearcut)
Oct. 6	1	0.00	0.00
	2	0.0004	0.0008
	3	0.0013	0.0025
	4	0.0034	0.0039
	5	0.0058	0.0062
	6	0.0071	0.0088
	7	0.0075	0.0102
	8	0.0071	0.0102
	9	0.0062	0.0098
	10	0.0044	0.0088
	11	0.0030	0.0071
	12	0.0026	0.0058
	13	0.0008	0.0043
Dec. 24	14	0.0004	0.0016
	15	0.00	0.00
	16	0.00	0.00
	17	0.00	0.00
	18	0.00	0.00
	19	0.00	0.00
	20	0.00	0.00
	21	0.00	0.00
	22	0.00	0.00
	23	0.00	0.00
	24	0.00	0.00
Feb. 28	25	0.00	0.0004
	26	0.00	0.0012
	27	0.00	0.0024
	28	0.00	0.0032
	29	0.00	0.0057
Mar. 31	30	0.0004	0.0089
	31	0.0012	0.0146
	32	0.0032	0.0210
	33	0.0057	0.0295
	34	0.0081	0.0384
	35	0.0129	0.0505
	36	0.0201	0.0667
	37	0.0270	0.0792
	38	0.0363	0.0916
	39	0.0443	0.1033
	40	0.0561	0.1088
	41	0.0689	0.1081
	42	0.0762	0.0916
	43	0.0822	0.0537
	44	0.0862	0.0291
	45	0.0862	0.0113
Jul. 6	46	0.0810	0.0008
	47	0.0746	0.00
	48	0.0621	0.00
	49	0.0459	0.00
	50	0.0294	0.00
	51	0.0186	0.00
	52	0.0113	0.00
	53	0.0073	0.00
	54	0.0040	0.00
Aug. 24	55	0.0008	0.00
	56	0.00	0.00
	57	0.00	0.00
	58	0.00	0.00
	59	0.00	0.00
	60	0.00	0.00
Sept. 30	61	0.00	0.00

Table III.18.—Digitized excess water distribution for the Central Sierra hydrologic province (7)—intermediate energy aspects.

Percentage in decimals of total annual flow which will occur during 6-day flow intervals

Block	6th day interval	Full Forest	Open (Clearcut)
Oct. 12	1	0.00	0.00
	2	0.0003	0.0004
	3	0.0005	0.0012
	4	0.0009	0.0033
	5	0.0024	0.0055
	6	0.0048	0.0076
	7	0.0048	0.0071
	8	0.0037	0.0063
	9	0.0025	0.0045
	10	0.0012	0.0025
	11	0.0006	0.0012
Dec. 12	12	0.0003	0.0004
	13	0.00	0.00
	14	0.00	0.00
	15	0.00	0.00
	16	0.00	0.00
	17	0.00	0.00
	18	0.00	0.00
	19	0.00	0.00
	20	0.00	0.00
Jan. 31	21	0.00	0.0004
	22	0.00	0.0008
	23	0.00	0.0016
	24	0.00	0.0028
	25	0.00	0.0048
	26	0.00	0.0069
	27	0.00	0.0101
	28	0.00	0.0130
	29	0.00	0.0168
Mar. 31	30	0.0008	0.0208
	31	0.0048	0.0281
	32	0.0125	0.0355
	33	0.0202	0.0437
	34	0.0278	0.0511
	35	0.0374	0.0650
	36	0.0471	0.0818
	37	0.0559	0.0993
	38	0.0663	0.1148
	39	0.0760	0.1131
	40	0.0860	0.0868
	41	0.0936	0.0609
	42	0.0948	0.0453
	43	0.0877	0.0298
	44	0.0743	0.0175
	45	0.0602	0.0073
	46	0.0463	0.0016
Jul. 12	47	0.0350	0.0004
	48	0.0254	0.00
	49	0.0150	0.00
	50	0.0069	0.00
	51	0.0032	0.00
Aug. 12	52	0.0008	0.00
	53	0.00	0.00
	54	0.00	0.00
	55	0.00	0.00
	56	0.00	0.00
	57	0.00	0.00
	58	0.00	0.00
	59	0.00	0.00
	60	0.00	0.00
Sept. 30	61	0.00	0.00

Table III.19.—Digitized excess water distribution for the Central Sierra hydrologic province (7)—high energy aspects.

Percentage in decimals of total annual flow which will occur during 6-day flow intervals

Block	6th day interval	Full Forest	Open (Clearcut)
	1	0.00	0.00
	2	0.00	0.00
	3	0.00	0.00
	4	0.00	0.00
	5	0.00	0.00
	6	0.00	0.00
Nov. 12	7	0.00	0.0004
	8	0.00	0.0020
	9	0.00	0.0028
	10	0.00	0.0040
Dec. 6	11	0.0004	0.0057
	12	0.0008	0.0069
	13	0.0020	0.0085
	14	0.0036	0.0093
	15	0.0053	0.0117
	16	0.0069	0.0134
	17	0.0098	0.0150
	18	0.0109	0.0166
	19	0.0133	0.0194
	20	0.0158	0.0215
	21	0.0186	0.0238
	22	0.0205	0.0266
	23	0.0238	0.0294
	24	0.0278	0.0338
	25	0.0323	0.0383
	26	0.0379	0.0443
	27	0.0451	0.0516
	28	0.0511	0.0641
	29	0.0591	0.0807
	30	0.0717	0.0975
	31	0.0950	0.1345
	32	0.0963	0.0758
	33	0.0865	0.0455
	34	0.0741	0.0366
	35	0.0579	0.0290
	36	0.0439	0.0202
	37	0.0350	0.0133
	38	0.0238	0.0089
	39	0.0170	0.0061
	40	0.0093	0.0024
Mar. 31	41	0.0040	0.0004
Apr. 6	42	0.0008	0.00
	43	0.00	0.00
	44	0.00	0.00
	45	0.00	0.00
	46	0.00	0.00
	47	0.00	0.00
	48	0.00	0.00
	49	0.00	0.00
	50	0.00	0.00
	51	0.00	0.00
	52	0.00	0.00
	53	0.00	0.00
	54	0.00	0.00
	55	0.00	0.00
	56	0.00	0.00
	57	0.00	0.00
	58	0.00	0.00
	59	0.00	0.00
	60	0.00	0.00
Sep. 30	61	0.00	0.00

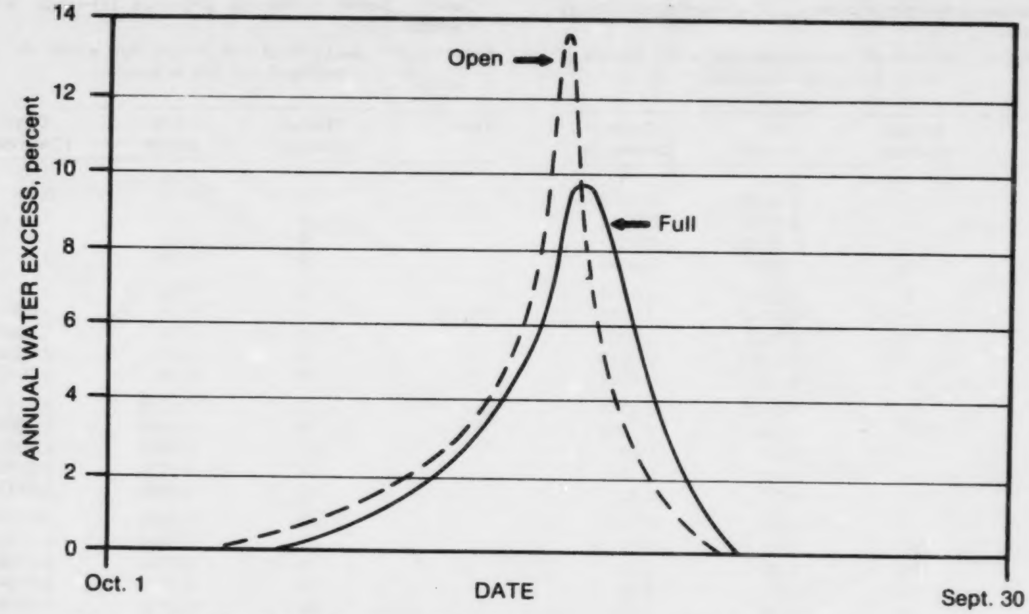


Figure III.67.—Potential water excess distribution graphs for Central Sierra hydrologic region (7)—treated conditions, low energy aspects.

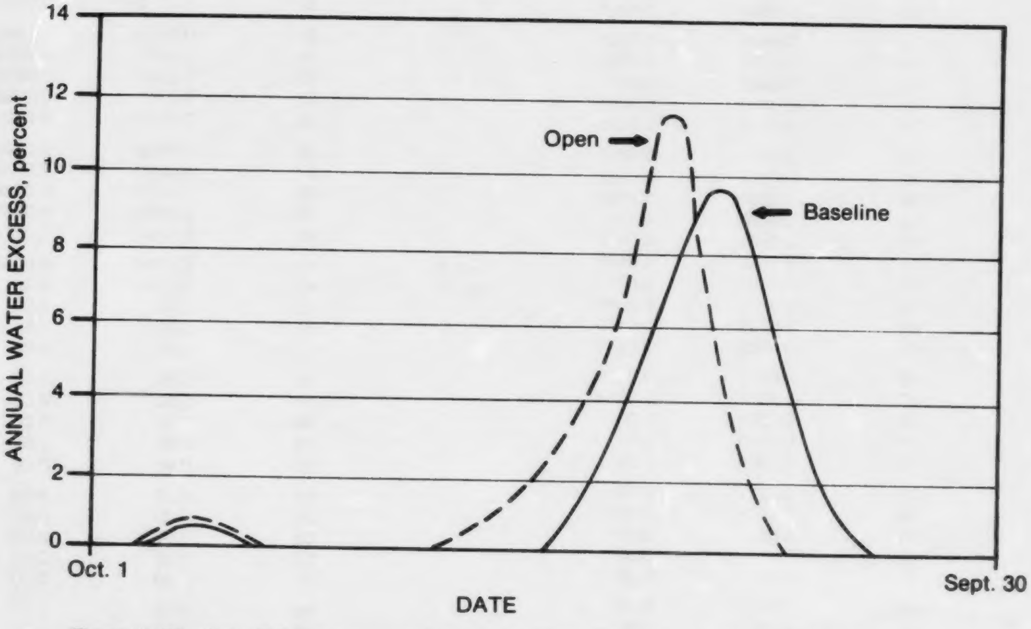


Figure III.68.—Potential water excess distribution graphs for Central Sierra hydrologic region (7)—treated conditions, intermediate energy aspects.

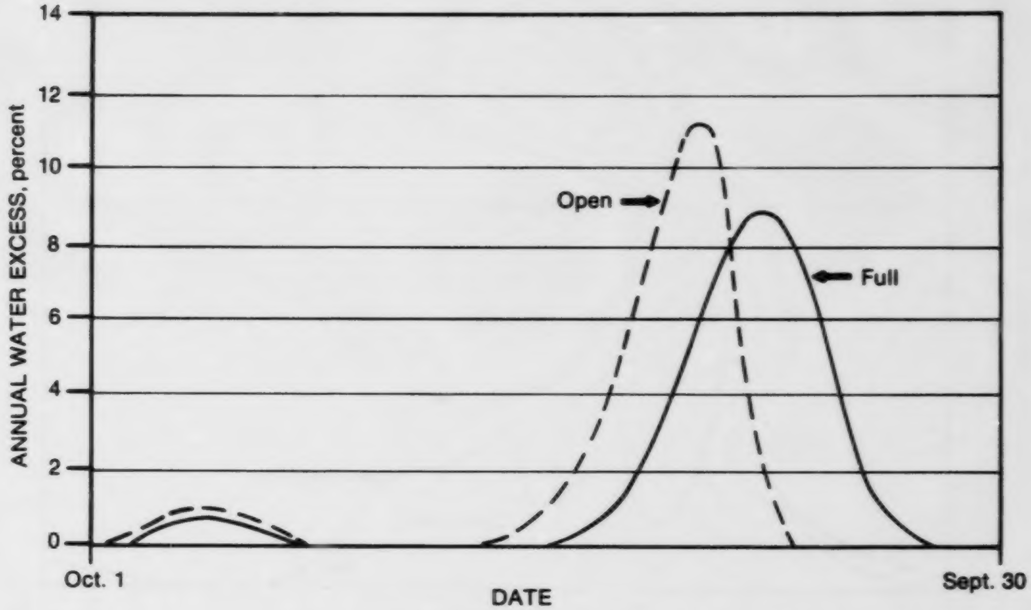


Figure III.69.—Potential water excess distribution graphs for Central Sierra hydrologic region (7)—treated conditions, high energy aspects.

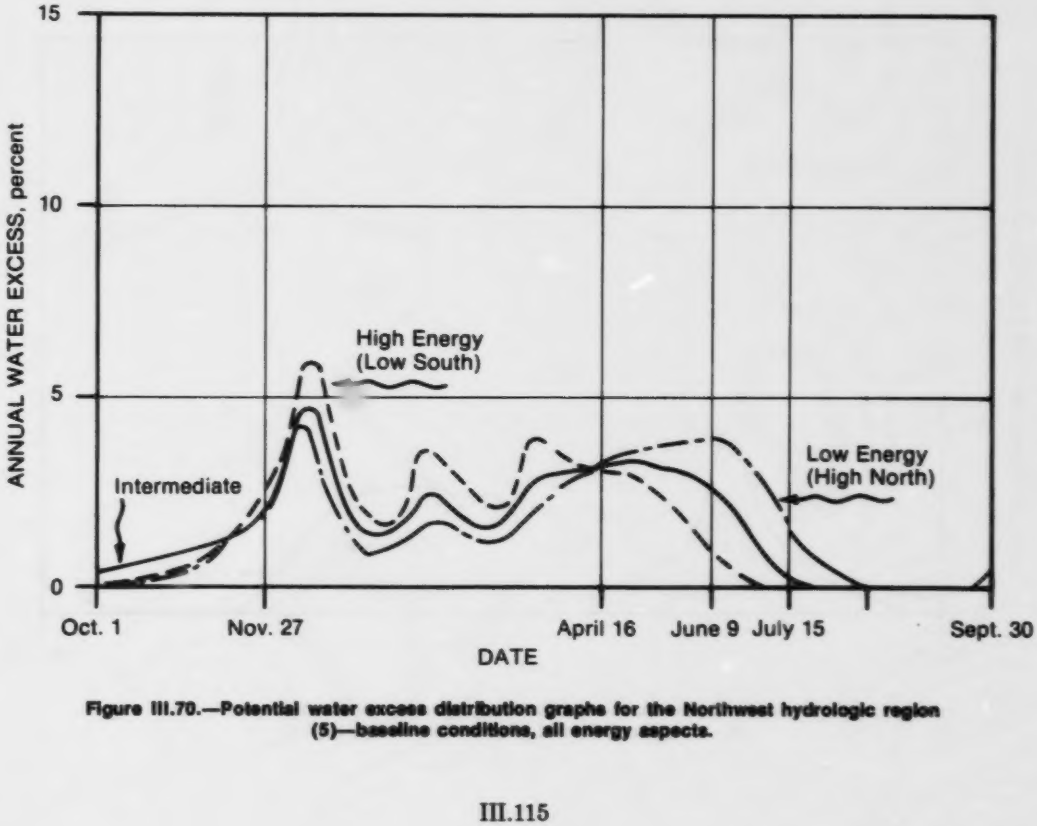


Figure III.70.—Potential water excess distribution graphs for the Northwest hydrologic region (5)—baseline conditions, all energy aspects.

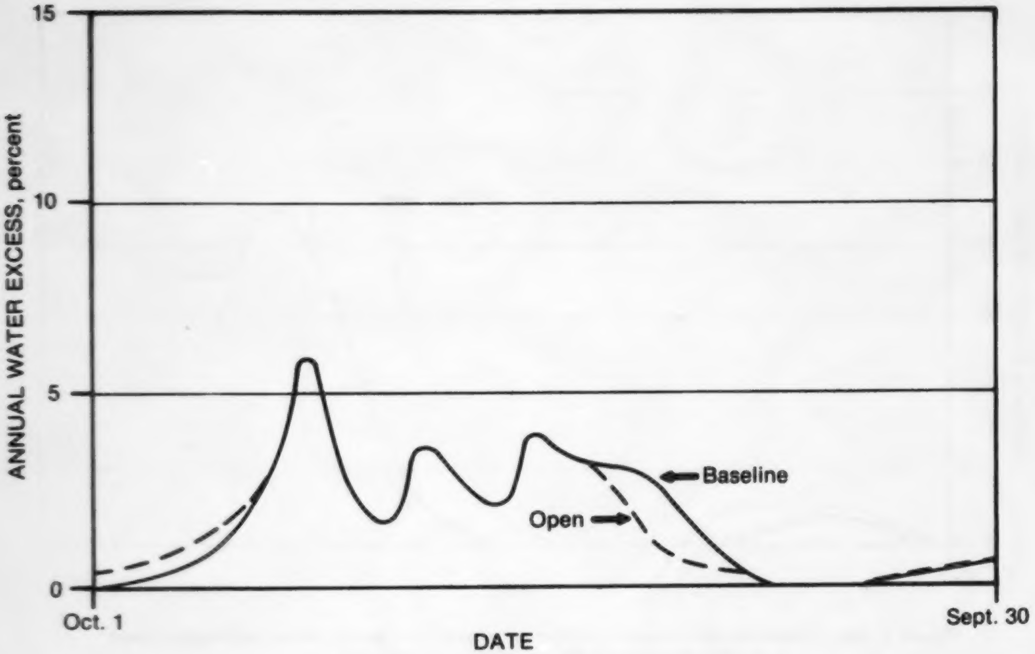


Figure III.71.—Potential water excess distribution graphs for the Northwest hydrologic region (5)—treated conditions, low energy aspect.

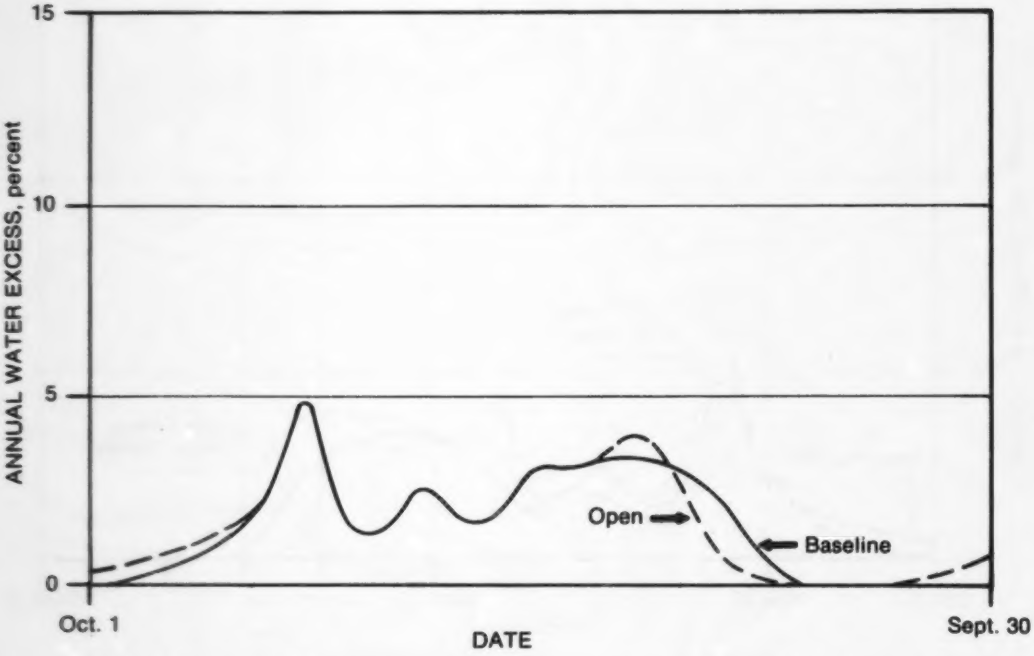


Figure III.72.—Potential water excess distribution graphs for the Northwest hydrologic region (5)—treated conditions, intermediate energy aspect.

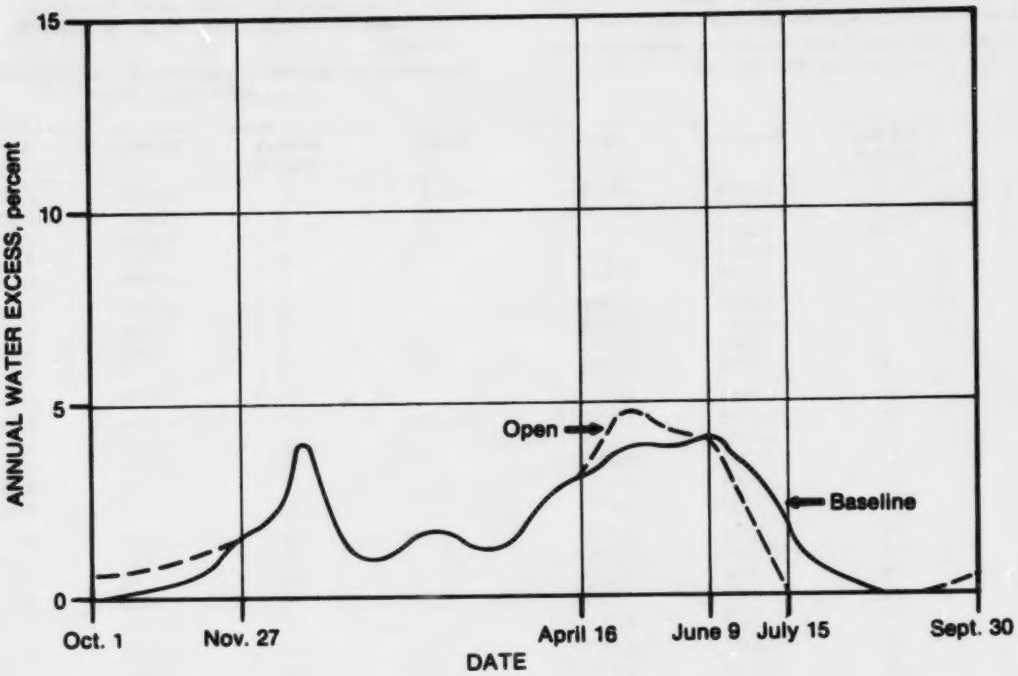


Figure III.73.—Potential water excess distribution graphs for the Northwest hydrologic region (5)—treated conditions, high energy aspects.

that rainfall can be normalized. They do, however, represent the nature of the change that may be expected. The limitations discussed in appendix III.C apply most directly to these portions of the distribution table.

Digitized excess water distributions provide a simplified means of estimating the potential change in flow distribution which might occur following a proposed silvicultural activity. Using inputs developed from the evapotranspiration calculations, an adjustment to the baseline condition for the proposed activity can be made in the following manner for each watershed compartment or energy aspect.

In region 4, the date of peak discharge from snowmelt for baseline conditions must be specified. Once the date for baseline has been established, the date for the open situation also becomes established. Interpolations of distribution graphs for intermediate vegetal states are also dated.

BASELINE DISTRIBUTION HYDROGRAPH

Baseline distribution graphs for the appropriate region can be selected from the previous discussion.

OPENINGS PRESENT?

If cover density is less than maximum, it must be determined if openings are present for the treatment or state in question.

OPEN DISTRIBUTION HYDROGRAPH

Distribution hydrographs for open conditions are given by hydrologic region or province and aspect. They can be found on the corresponding full forested distribution hydrograph figures and tables provided above.

Table III.20—Digitized excess water distribution for the Northwest hydrologic province (5)—low energy aspects.

Percentage in decimals of total annual flow which will occur during 6-day flow intervals

Block	6th day interval	Baseline	Open
Oct. 1	1	0.0008	0.0056
	2	0.0020	0.0064
	3	0.0028	0.0068
	4	0.0032	0.0076
	5	0.0040	0.0080
	6	0.0048	0.0092
	7	0.0061	0.0108
	8	0.0085	0.0120
	9	0.0116	0.0136
Nov. 27	10	0.0153	0.0153
	11	0.0185	0.0185
	12	0.0204	0.0204
	13	0.0253	0.0253
	14	0.0401	0.0401
	15	0.0293	0.0293
	16	0.0200	0.0200
	17	0.0141	0.0141
	18	0.0104	0.0104
	19	0.0100	0.0100
	20	0.0116	0.0116
	21	0.0128	0.0128
	22	0.0153	0.0153
	23	0.0157	0.0157
	24	0.0149	0.0149
	25	0.0132	0.0132
	26	0.0120	0.0120
	27	0.0120	0.0120
	28	0.0136	0.0136
	29	0.0161	0.0161
	30	0.0192	0.0192
	31	0.0233	0.0233
	32	0.0277	0.0277
	33	0.0313	0.0313
Apr. 16	34	0.0325	0.0359
	35	0.0361	0.0423
	36	0.0382	0.0470
	37	0.0385	0.0467
	38	0.0385	0.0447
	39	0.0393	0.0423
	40	0.0393	0.0411
	41	0.0401	0.0403
	42	0.0397	0.0395
	43	0.0369	0.0339
	44	0.0337	0.0255
	45	0.0281	0.0179
	46	0.0208	0.0092
	47	0.0169	0.0004
	48	0.0121	0.00
	49	0.0089	0.00
	50	0.0085	0.00
	51	0.0040	0.00
	52	0.0028	0.00
	53	0.0012	0.00
	54	0.00	0.00
	55	0.00	0.00
	56	0.00	0.00
	57	0.00	0.00
	58	0.00	0.0008
	59	0.00	0.0020
	60	0.00	0.0036
Sept. 30	61	0.00	0.0048

Table III.21—Digitized excess water distribution for the Northwest hydrologic province (5)—intermediate energy aspects.

Percentage in decimals of total annual flow which will occur during 6-day flow intervals

Block	6th day interval	Baseline	Open
Oct. 1	1	0.0004	0.0044
	2	0.0012	0.0048
	3	0.0020	0.0057
	4	0.0028	0.0065
	5	0.0040	0.0073
	6	0.0053	0.0089
	7	0.0065	0.0105
	8	0.0090	0.0122
	9	0.0119	0.0147
	10	0.0153	0.0171
Nov. 27	11	0.0198	0.0198
	12	0.0259	0.0259
	13	0.0354	0.0354
	14	0.0479	0.0479
	15	0.0437	0.0437
	16	0.0306	0.0306
	17	0.0214	0.0214
	18	0.0148	0.0148
	19	0.0139	0.0139
	20	0.0165	0.0165
	21	0.0206	0.0206
	22	0.0247	0.0247
	23	0.0243	0.0243
	24	0.0214	0.0214
	25	0.0198	0.0198
	26	0.0189	0.0189
	27	0.0206	0.0206
	28	0.0231	0.0231
	29	0.0272	0.0272
	30	0.0330	0.0330
	31	0.0330	0.0330
	32	0.0326	0.0326
	33	0.0322	0.0322
	34	0.0330	0.0330
Apr. 16	35	0.0330	0.0354
	36	0.0338	0.0383
	37	0.0330	0.0392
	38	0.0322	0.0370
	39	0.0314	0.0334
	40	0.0296	0.0293
	41	0. 0272	0.0183
	42	0.0247	0.0118
	43	0.0214	0.0065
	44	0.0165	0.0036
	45	0.0123	0.0024
	46	0.0070	0.0012
	47	0.0040	0.0004
	48	0.0012	0.00
	49	0.00	0.00
	50	0.00	0.00
	51	0.00	0.00
	52	0.00	0.00
	53	0.00	0.00
	54	0.00	0.00
	55	0.00	0.0004
	56	0.00	0.0008
	57	0.00	0.0016
	58	0.00	0.0024
	59	0.00	0.0032
	60	0.00	0.0040
Sept. 30	61	0.00	0.0044

Table III.22—Digitized excess water distribution for the Northwest hydrologic province (5)—high energy aspects. Percentage in decimals of total annual flow which will occur during 6-day flow intervals

Block	6th day interval	Baseline	Open
Oct. 1	1	0.0004	0.0051
	2	0.0008	0.0053
	3	0.0012	0.0057
	4	0.0020	0.0065
	5	0.0032	0.0077
	6	0.0050	0.0100
	7	0.0066	0.0114
	8	0.0091	0.0158
	9	0.0127	0.0168
	10	0.0169	0.0237
	11	0.0231	0.0279
Nov. 27	12	0.0322	0.0322
	13	0.0425	0.0425
	14	0.0595	0.0595
	15	0.0540	0.0540
	16	0.0397	0.0397
	17	0.0264	0.0264
	18	0.0202	0.0202
	19	0.0174	0.0174
	20	0.0197	0.0197
	21	0.0314	0.0314
	22	0.0360	0.0360
	23	0.0325	0.0325
	24	0.0292	0.0292
	25	0.0264	0.0264
	26	0.0223	0.0223
	27	0.0210	0.0210
	28	0.0251	0.0251
	29	0.0371	0.0371
	30	0.0392	0.0392
	31	0.0359	0.0359
	32	0.0338	0.0338
	33	0.0322	0.0322
	34	0.0310	0.0310
Apr. 16	35	0.0306	0.0252
	36	0.0305	0.0199
	37	0.0277	0.0142
	38	0.0239	0.0096
	39	0.0206	0.0079
	40	0.0157	0.0063
	41	0.0107	0.0042
	42	0.0074	0.0038
	43	0.0044	0.0029
	44	0.0020	0.0021
	45	0.0008	0.0009
	46	0.00	0.00
	47	0.00	0.00
	48	0.00	0.00
	49	0.00	0.00
	50	0.00	0.00
	51	0.00	0.00
	52	0.00	0.00
	53	0.00	0.00
	54	0.00	0.0004
	55	0.00	0.0009
	56	0.00	0.0017
	57	0.00	0.0025
	58	0.00	0.0033
	59	0.00	0.0041
	60	0.00	0.0047
Sept. 30	61	0.00	0.0048

INTERPOLATED DISTRIBUTION HYDROGRAPH

Distribution hydrographs for partial cuts are interpolated from full forested (complete hydrologic utilization) and open distribution hydrographs.

Interpolation of distribution graphs is straightforward and linear, although hydrologic response to vegetation change is not linear. For any partial reduction in C_d from C_{dmax} (baseline), the interpolated distribution graph is obtained in the following manner.

For each 6-day period, calculate the difference between the baseline and open percentage of flow, multiply the difference by the decimal percentage of C_d change from C_{dmax}. Now add the product to the baseline value to obtain the interpolated distribution (i.e., if C_{dmax} is .40 and is reduced to .30, this represents a 25-percent reduction in cover density). The intermediate distribution would be a point 25 percent of the way between baseline and open values.

WEIGHTED WATER AVAILABLE FOR ANNUAL STREAMFLOW

Water potentially available for streamflow (P-ET) has already been estimated for all conditions and treatments in the preceding section on ET estimation. The objective now is to apportion that annual flow using the appropriate distribution graph.

SILVICULTURAL STATE HYDROGRAPH

Potential streamflow hydrographs for each silvicultural treatment (items 6, 9, 12, 15, 18, 21) are obtained by multiplication of the distribution hydrograph value of each 6-day flow increment by adjusted water available for annual streamflow (items 30-35 worksheets III.5 or III.6). Area-inch values (items 5, 8, 11, 14, 17, 20) are then converted to cubic feet per second (cfs) using the following formula:

$$\text{(cfs)} = \frac{\text{(inches) (watershed area in acres)}}{\text{(12 in/ft) (1.98) (number of days in interval)}} \qquad \text{(III.16)}$$

ALL SILVICULTURAL STATES CONSIDERED?

The hydrograph generated for each treatment represents the weighted contribution to total watershed flow. If the actual hydrograph from the treatment (or prescription) is desired, the hydrograph should be reverse weighted (multiplied by watershed area/treatment or prescription area).

ALL SILVICULTURAL PRESCRIPTIONS CONSIDERED?

At this point, a distribution of annual flow for one prescription has been completed. All prescriptions within an energy aspect must be completed prior to looping an energy aspect.

ALL ENERGY ASPECTS CONSIDERED?

One energy aspect has been completed. To complete analysis for one condition, repeat for all energy aspects.

WATERSHED HYDROGRAPH

Summation of the 6-day flow increments for each silvicultural state or treatment hydrograph by prescription and energy aspect yields the composite hydrograph for the condition. Since all estimates of flow were area weighted, the hydrograph values are additive.

ALL CONDITIONS CONSIDERED?

The methodology is structured so the hydrograph for one condition must be constructed before the hydrograph for a second condition can be calculated.

The following is the methodology appropriate for region 1.

NEW ENGLAND/LAKE STATES REGION (1)

The presentation of flow distribution is different for the New England/Lake States hydrographic region (1) than for the other snow dominant regions and provinces because rainfall, as well as snowmelt, plays a dominant role in the hydrologic cycle there. For this reason, the output from the simulations is presented in flow duration curves rather than time dependent distribution graphs. The reasoning for using one or the other is explained in appendix III.C.

BASELINE AND OPEN FLOW DURATION CURVES

As in the other regions and provinces discussed here, simulations for a number of water years were made under fully forested baseline conditions, under a 50-percent reduction in cover density, under a 60- and 90-percent cover density, and under a fully open condition. The baseline flow duration curves for the New England/Lake States hydrographic region are presented in figure III.74. Peak flows were simulated to be slightly greater on the low energy (north) aspects due to a more concentrated melt period. Simulations were not sensitive to any aspect differences in potential low flows which would come in both midwinter and late summer.

The procedure for modifying the flow duration curve is a modification of the technique presented for the rain dominant hydrologic regions (2, 3, 5, 6, and 7). Baseline and open potential streamflow are determined with techniques presented in the streamflow analysis for rain dominated regions.

If the calculated potential baseline flow differs from that presented in figures III.75 to III.77, replot the flow duration curve. A number of points along the flow duration curve should be read and the flow (y axis) should be multiplied by the ratio of expected site specific baseline annual flow to annual flow represented by flow duration curve. The new flow (y) is then replotted at the same duration. This will yield a new flow duration curve adjusted for the difference in potential baseline flow during the year of silvicultural activity and the normalized year presented in this handbook.

The baseline flow procedure is repeated for open conditions. Worksheet III.3 of the section on rain dominated regions is helpful for these calculations.

COVER DENSITY REDUCTION

The shift in the baseline flow duration curve to reflect silvicultural states is a function of cover density reduction. Percent of cover density reduction must be specified. Guidelines for assessing cover density may be found in the section on evapotranspiration estimation for snow dominated regions.

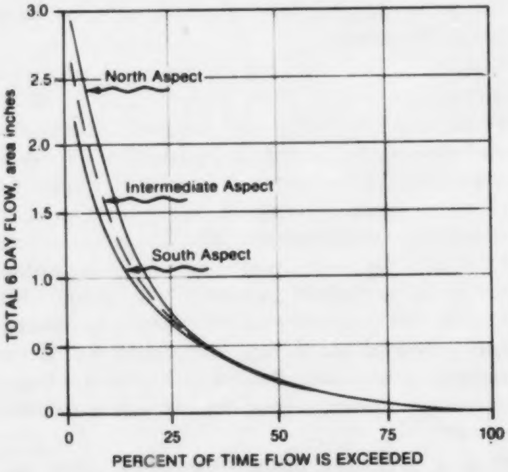


Figure III.74.—Potential excess water flow duration curve for the New England/Lake States hydrologic region (1)—baseline conditions, all energy aspects.

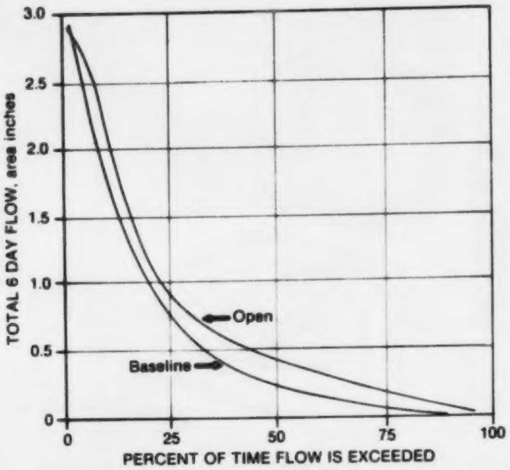


Figure III.75.—Potential excess water flow duration curve for the New England/Lake States hydrologic region (1)—treated conditions, low energy aspects.

EXISTING AND PROPOSED FLOW DURATION CURVES

Figure III.77 represents the shift which occurs in the flow duration curve for three levels of harvest — a 60-percent, 90-percent, and 100-percent reduction in cover density. The shift is not linear. At lower intensity cuts, much of the shift occurs in the lower flows, primarily late summer. As the intensity of harvest increases, an effect on larger (spring

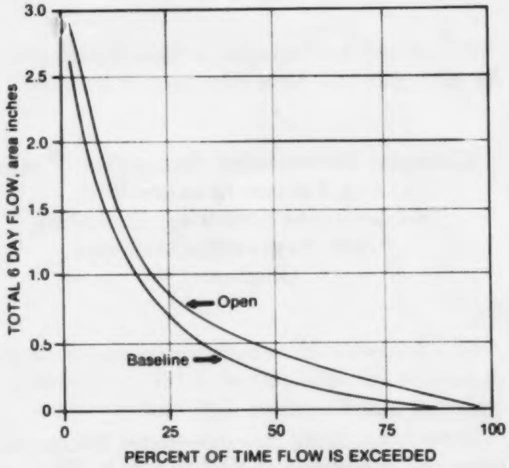


Figure III.76.—Potential excess water flow duration curve for the New England/Lake States hydrologic region (1)—treated conditions, intermediate energy aspects.

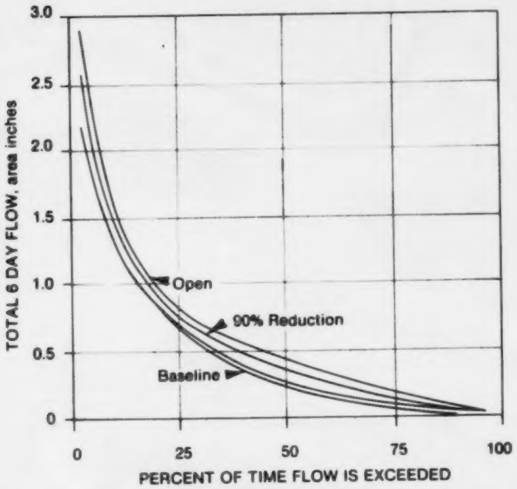


Figure III.77.—Potential excess water flow duration curve for the New England/Lake States hydrologic region (1)—treated conditions, high energy aspects.

melt) flows becomes more apparent. Interpolation between calculated baseline and calculated open flow duration curves will give the flow duration curve for the silvicultural activity condition. This is an arbitrary interpolation. Guidelines for interpolation are implied by figure III.77.

END

Watershed hydrographs or flow duration curves for all conditions have now been calculated.

Example: Determining Streamflow Timing And Volume Changes With Silvicultural Activities, Excluding "New England/Lake States (Region 1)"

The following illustration presents a stepwise procedure for application of the methodology for Region 4 and Provinces 5, 6, and 7.

Directly following this procedural discussion are examples of worksheets III.7 and III.8. They are illustrative of the data required for completing the methodology.

Step 1. Using appropriate figures and worksheets III.5 and III.6 as guides, calculate the annual potential streamflow by silvicultural state for both existing and proposed conditions. Assume the area of the watershed is 100 acres. Annual potential streamflows have been area weighted. A typical result is shown below.

Silvicultural activity	Existing condition		
	Excess water (in)	Watershed area represented (%)	Weighted excess water (in)
Forested impacted	12	.200	2.4
Forested unimpacted	15	.600	9.0
Clearcut	20	.200	4.0
Partial cut	0	0	0
Total flow from watershed			15.4
	Proposed condition		
Forested impacted	12	.250	3.0
Forested unimpacted	15	.175	2.6
Clearcut	20	.450	9.0
Partial cut	16	.125	2.0
Total flow from watershed			16.6

Step 2. This step applies to the Rocky Mountain/Inland Intermountain hydrographic region (4) only. The date on which the peak snowmelt flow will occur must be known. Mark the digitized excess water distribution graph (baseline only). Peak flow rate is represented by the largest flow percentage in the baseline column of tables III.11 to III.13. Once the date of the expected peak has been established, dates of the other components can also be established in 6-day increments.

Step 3. Select the appropriate digitized excess water distribution from tables III.11 to III.22. Enter baseline values for forested unimpacted and forested impacted silvicultural activities in worksheet III.7, columns (4) and (10). Repeat for clearcut (open) values in column (10). Interpolate between open and baseline distributions to obtain the partial cut digitized distribution. Enter the partial cut distribution in column (16). Repeat this procedure as necessary until existing and proposed conditions are considered. If the watershed has been divided into subunits based on energy aspect, repeat the procedure for each subunit.

Step 4. Multiply each silvicultural state distribution graph value by its corresponding annual potential streamflow for that state. Enter the products in the "inches" column for each state.

Step 5. Convert "inches" into cubic feet per second (cfs) using the formula —

$$(\text{cfs}) = \frac{(\text{inches})\ (\text{watershed area in acres})}{(12\ \text{in/ft})\ (1.98)\ (\text{number of days in interval})} \qquad (\text{III}.16)$$

Step 6. For each interval on each worksheet add (cfs) columns for all silvicultural states. Enter the sums in column (19). The composite hydrograph is given in column (19). If the watershed has been divided into subunits, each subunit composite hydrograph is weighted by subunit percent of total watershed area. Existing and proposed condition hydrographs are calculated separately.

The preceding methodology assumes that the effect of increasing the amount of vegetation removed is linear. This is not generally true since only two points were simulated — no response and full response; it is impossible to make an interpolation other than linear. Any error due to this would probably result in overestimating the impact of lesser activities. This has a conservative effect on the estimations.

PROCEDURAL DESCRIPTION: DETERMINING SOIL MOISTURE CHANGES AND INDIVIDUAL EVENT STORM RESPONSE

Earlier sections of this chapter have emphasized changes in 6- and 7-day intervals for either evapotranspiration, soil moisture, or water available for flow. Responses to individual events — primarily storm runoff — were not dealt with. This section now addresses that issue.

The methodologies already developed assume that water infiltrates into the undisturbed forest floor, but there are exceptions. Two factors associated with stormflow production can be altered by silvicultural activities: (1) The infiltration characteristics of the surface, and (2) alteration by disturbance of the storage capacity in the soil. (Distribution and melt rate of winter snowpack can also be affected by tree removal. Changes in both the amount and melt rate of the pack can cause either the infiltration rate or storage capacity of the soil profile to be exceeded; this, in turn, causes higher peak flow rates. This occurrence is not treated as storm runoff, however, but was previously treated as flow change.)

To address the first factor, most conventional silvicultural practices, excluding site preparation, do not significantly disturb the soil surface, except for the access and decking systems. These systems have the potential for changing slope hydrology in that subsurface soil water is intercepted by road cuts and routed over the surface along with the rain falling directly on these surfaces. There is a potential for altering the timing and delivery route to the channel of 10 to 15 percent of the precipitation. The impact of this potential on the storm hydrograph can be expected to be variable — the stormflow peak and volume may or may not be increased by water from the access system. This depends on how the rerouted water enters the system. The net effect can be to reduce or augment the peak, depending upon normal basin response. However, consistent with best management practices, if the access system is properly designed, laid out, and drained, then the intercepted water should be distributed back over the basin surface and allowed to reinfiltrate into the soil mantle (provided that storage is available). This minimizes the impact on the hydrograph.

To address the second factor, the most significant impact that silvicultural practices can have on stormflow is their effect on antecedent storage. As will be shown in the discussions on soil moisture deficits, as the intensity of cut increases, the deficit or storage capacity at any point in time decreases. With less storage capacity, more of the precipitation appears as stormflow.

Much of the potential for non-point source pollution associated with silvicultural activities is associated with individual storm events. The impact is not only as stream power as a function of volume and peak flow rates, but also as the opportunity for sediment delivery. Therefore, the hydrologist or engineer usually needs to evaluate the expected response to some "design" storm.

The general purpose of the hydrology section is to present a methodology for estimating the hydrologic impact of silvicultural activities, including impacts on storm response. However, the state-of-the-art in hydrology does not allow the presentation of a regionalized, process-oriented methodology for evaluating the impact, if any, of site disturbance on the storm hydrograph.

Instead a qualitative evaluation will have to be made based on how, when, and where the disturbance will be made, and how such disturbances might affect the hill slope hydrology.

If the pathway water takes to the channel is not altered by the silvicultural activity — and there is little reason to believe it will be if best management practices are followed — then the only other impact which can occur will be a reflection of the change in soil moisture storage capacities.

The problem of flood forecasting is twofold. First, the impact silvicultural activities can have on the soil water regime should be evaluated; secondly, techniques for predicting stormflow should be discussed. If the primary interest is in the potential for change, then the soil water evaluation discussed next will define those periods when significant changes can occur. Subsequent development will allow design storm selection.

Like the other procedures, the soil water methodology varies by region, primarily because of the nature of the model output. Once the moisture status has been determined, the applications of the stormflow prediction procedure would be similar, although the relative weight of design criteria may vary by region.

SOIL MOISTURE CHANGES
HUMID CLIMATES, (RAIN DOMINATED REGIONS) PACIFIC COAST REGION, LOW ELEVATION
(PROVINCES 5, 6, 7)
APPALACHIAN MOUNTAIN AND HIGHLANDS (REGION 2)
GULF AND ATLANTIC COASTAL PLAIN AND PIEDMONT
(REGION 3)

Dealing adequately with soil moisture depletion rates and deficits is more difficult in a handbook based on regions than is dealing with either evapotranspiration or the potential streamflow. Both evapotranspiration and streamflow follow seasonal patterns, and they have predictable regional relationships. Soil moisture follows the same general pattern; however, soil moisture deficits (or differences in deficits between sites of pre- or post-silvicultural activity) can be eliminated in a single storm event at any time without any obvious reflection in evapotranspiration or flow.

In this instance, the technique used to predict the soil moisture distribution is by simulation; other researchers have used different techniques. Troendle (1970), Patric (1974), and others have presented results of studies investigating baseline and observed changes in soil moisture following various cutting practices. Tichendorf (1969), Helvey and others (1972), Kochenderfer and Troendle (1971), and others have developed prediction equations to estimate soil moisture as a function of descriptive parameters such as position on slope, aspect, basal area, soil factors, and antecedent rainfall. These local techniques, if applicable, may be better for defining a site specific baseline soil moisture level than the normalized curve to be presented. Like the expected flows, what is most important is not necessarily the absolute value, but the ability to adjust the soil moisture level appropriately to evaluate the potential impact of a proposed activity.

Seasonal deficits in soil moisture (or soil moisture storage capacity) for a particular region should be estimated from figures III.78, III.79, or III.80 directly. Then, for the proposed activity, determine the modifier coefficient, by season, from figure III.81, III.82, or III.83.

Multiplying the modifier coefficient by the baseline deficit will give the expected post-activity level. The difference between the pre-activity and post-activity deficit is the change that can be expected as a result of the activity. By the same token, the pre-activity level for any past history can be determined by adjusting the baseline curve for present stand conditions. Figures III.78 to III.80 represent the average simulated soil moisture deficit for the root zone in each of the regions. Although figures III.78 to III.80 have been smoothed, the deficit at the end of the four seasons has been plotted. It should be kept in mind, however, that these represent average conditions which could be modified or eliminated at any time by a single storm event.

Modifier coefficients (figs. III.81 to III.83) are to be applied to the baseline deficit extracted in order to adjust for various levels of leaf area index. These are representative curves and will give an index to the change in antecedent moisture that can be expected as a result of the proposed activity. Although the effect varies with storm size, soil depth, and available storage capacity, antecedent rainfall can eliminate the deficit at any time; discretion must be used in evaluating whether or not conditions may be wetter or drier than "normal."

Adjustments in the baseline or existing soil moisture deficit can also be made for differing rooting or soil depth. The changes in evapotranspiration resulting from altering rooting depths were almost a direct reflection of the changes in soil moisture storage. Therefore, the deficits expressed in figures III.78 to III.80 can be adjusted for differing depth by multiplying the appropriate deficit by the modifier coefficient expressed in figures III.81 to III.83.

In the southern Appalachians, soils are deeper (in excess of 6-8 feet) than in the rest of the region, and the soil moisture distribution is more like that of the Coastal Plain/Piedmont region. Therefore, figure III.80 may be substituted for figure III.79, and figure III.83 for figure III.82. This will allow an estimate of the baseline distribution and post-activity relationships for the generally deeper soils in the southern Appalachians.

The simulations indicate (as did the observations reference) that aspect and, to some extent, latitude did affect the soil water deficits. However, the error associated with predicting them is such that the site specific effect cannot be isolated. Basically, simulated deficits appeared greater on southerly aspects and in more southerly locations than on northern aspects and locations.

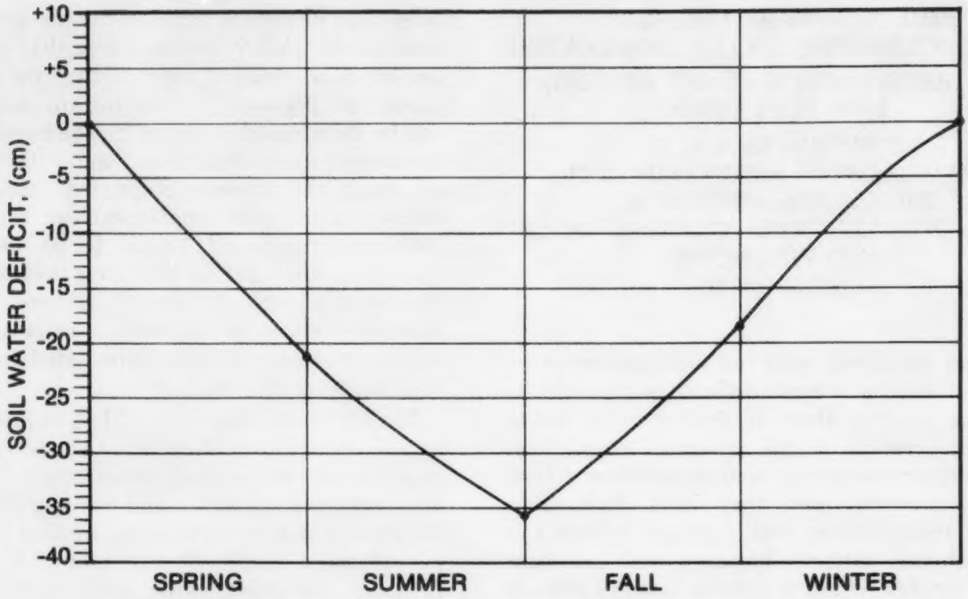


Figure III.78.—Average simulated soil moisture deficit, root zone only (upper 3 feet), for the Pacific Coast hydrologic provinces—Northwest (5), Continental/Maritime (6), and Central Sierra (7).

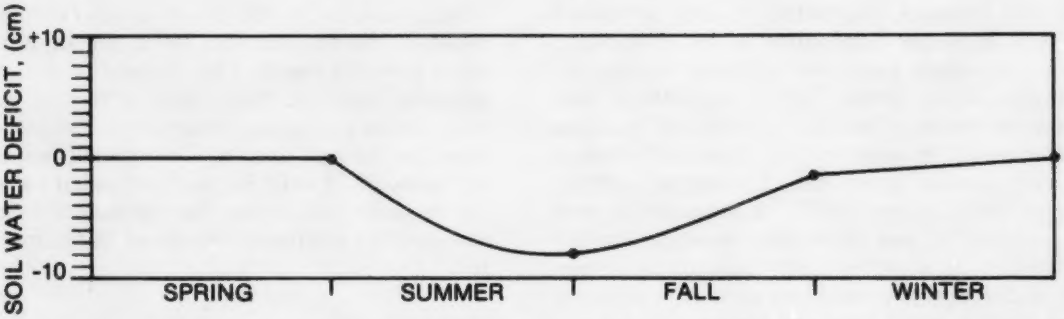


Figure III.79.—Average simulated soil moisture deficit, root zone only (upper 3 feet), for the Appalachian Mountain and Highlands hydrologic region (2).

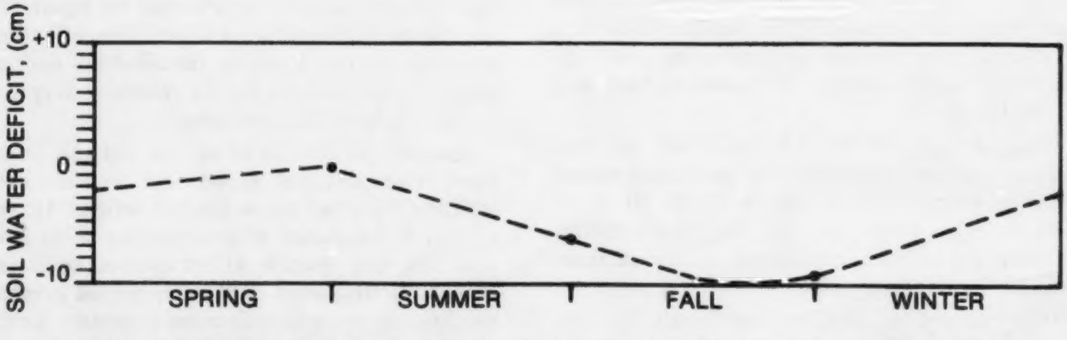


Figure III.80.—Average simulated soil moisture deficit, root zone only (upper 3 feet), for the Eastern Coastal Plain and Piedmont hydrologic region (3).

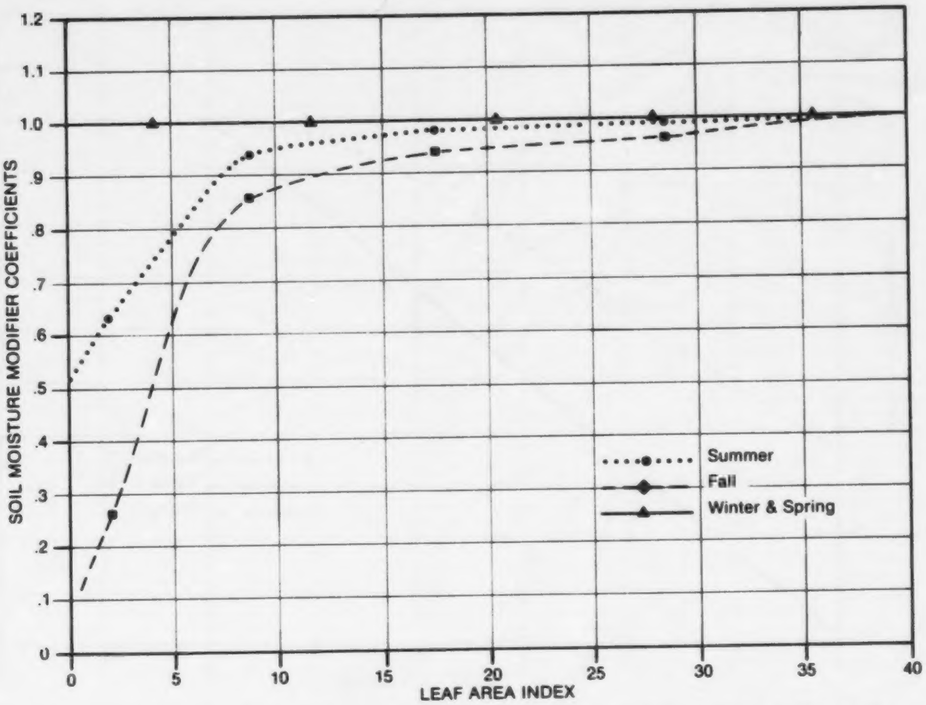


Figure III.81.—Seasonal soil moisture deficit modifier coefficients for the Pacific Coast hydrologic provinces—Northwest (5), Continental/Maritime (6), and Central Sierra (7).

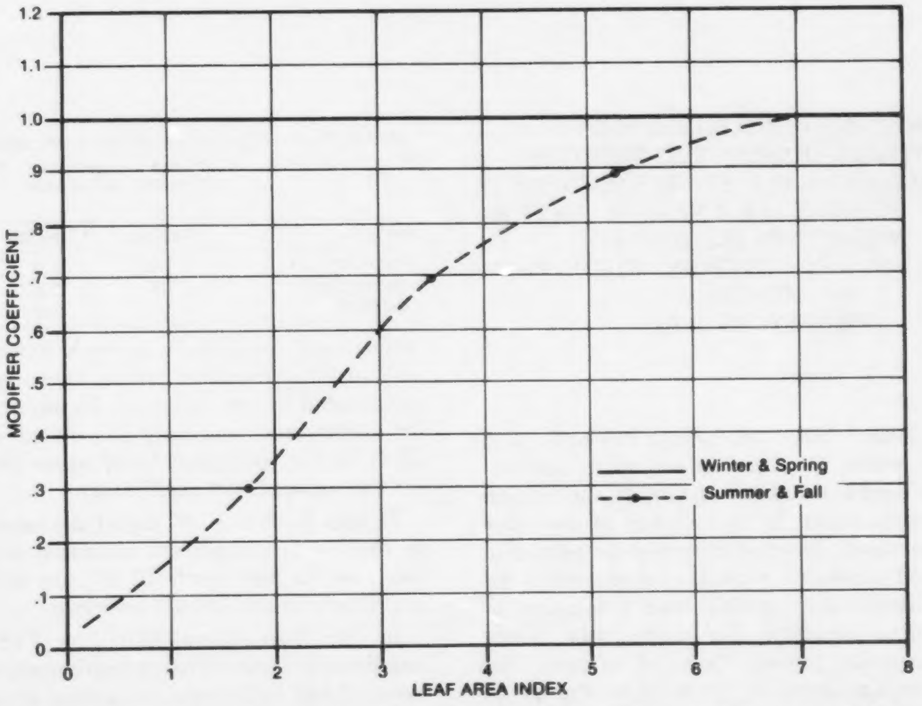


Figure III.82.—Seasonal soil moisture deficit modifier coefficients for the Appalachian Mountains and Highlands hydrologic region (2).

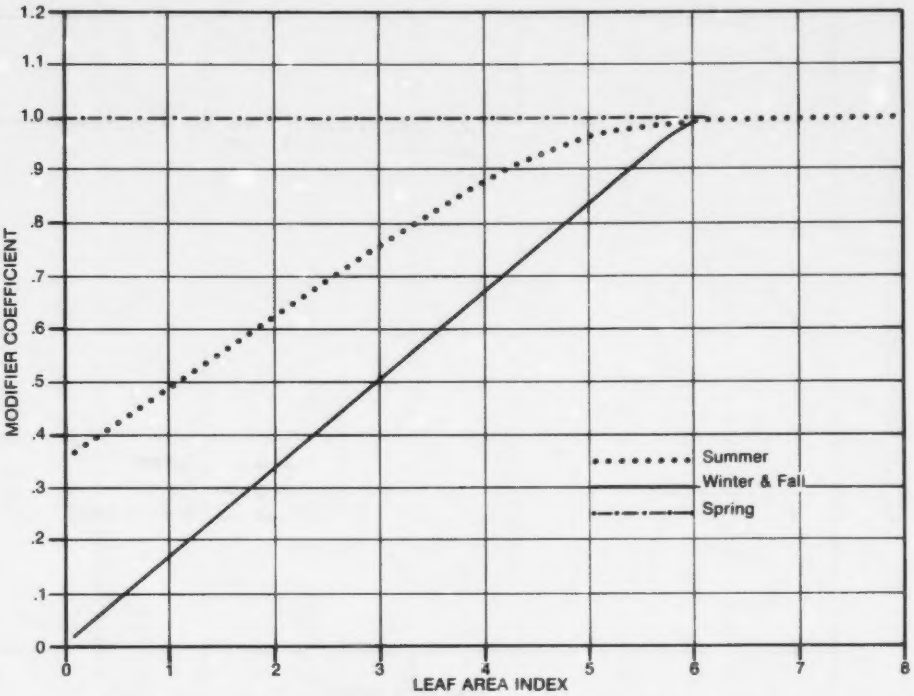


Figure III.83.—Seasonal soil moisture deficit modifier coefficients for the Eastern Coastal Plains and Piedmont hydrologic region (3).

SOIL MOISTURE CHANGES (SNOWFALL DOMINATED REGIONS) NEW ENGLAND/LAKE STATES (REGION 1) ROCKY MOUNTAIN/INLAND INTER-MOUNTAIN (REGION 4) PACIFIC COAST, HIGHER ELEVATION ZONES (PROVINCES 5, 6, 7)

In the Rocky Mountain/Inland Intermountain hydrologic region (4), baseline soil water requirements for conditions of full hydrologic utilization are plotted in figure III.84 for each of the three seasons discussed. Baseline relationships plotted in figure III.84 represent recharge requirements for moderate depth soils (which have 5.5 inches of water holding capacity). For deeper soils (water holding capacity greater than 10 inches), the recharge requirements in figure III.84 should be multiplied by the following coefficients:

Table III.23.—Soil moisture adjustment coefficients for the Rocky Mountain/Inland Intermountain hydrologic region (4) by aspect/elevation and season

Aspect	Feb. 28	June 30	Sept. 30
High north	1.0	1.0	1.0
Intermediate	1.4	1.2	1.2
Low south	1.7	1.3	1.4

Adjustment coefficients for soils having between 5.5 and 10 inches water holding capacity can be approximated by interpolation. To adjust the deficit for deeper soils, multiply the deficit from figure III.84 by the coefficient listed above (table III.23) (or the interpolated coefficient).

Figures III.85 to III.87 depict the baseline as well as the 50- to 100-percent reduction soil moisture levels for the high north (III.85), low south (III.86), and intermediate (III.87) positions.

In the Continental/Maritime Province (6), baseline soil water recharge requirements for conditions of full hydrologic utilization are plotted in figure III.88.

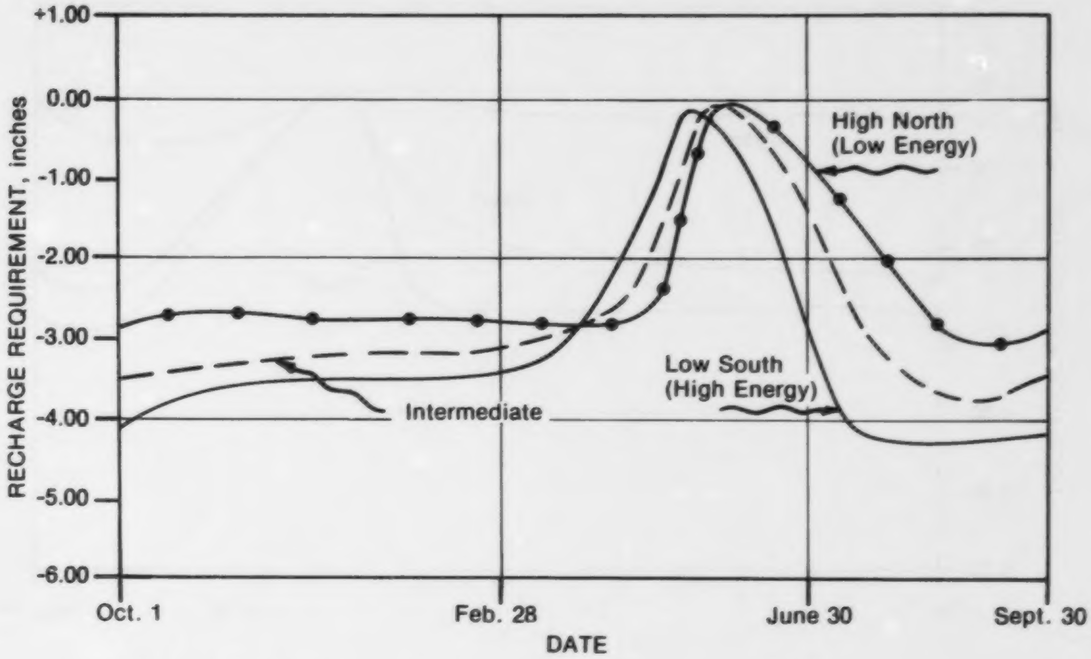


Figure III.84.—Baseline soil water requirement relationships for the Rocky Mountain/Inland Intermountain region (moderate soil depth).

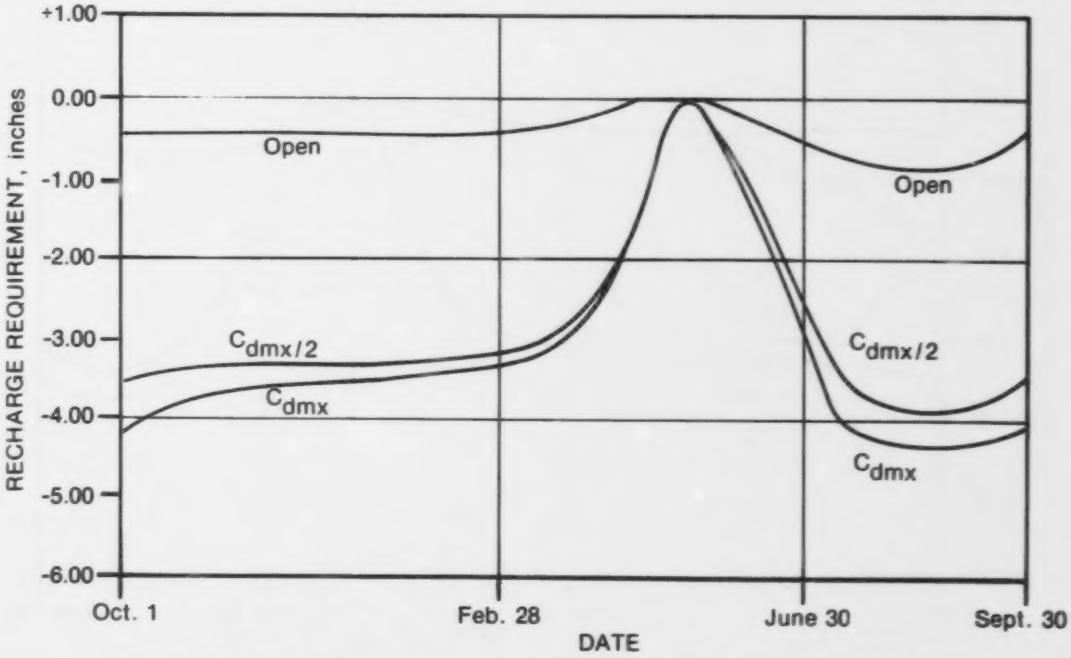


Figure III.85.—Seasonal soil moisture recharge requirements for the Rocky Mountain/Inland intermountain hydrologic region (4)—low energy aspects (high north).

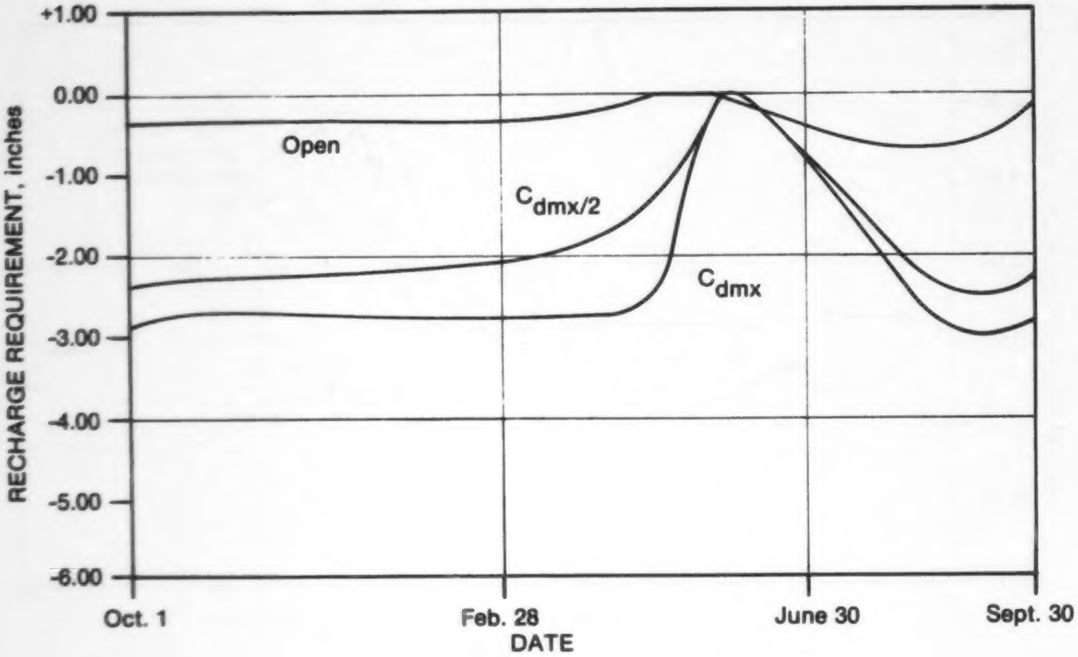


Figure III.86.—Seasonal soil moisture recharge requirements for the Rocky Mountain/Inland Intermountain hydrologic region (4)—high energy aspects (low south).

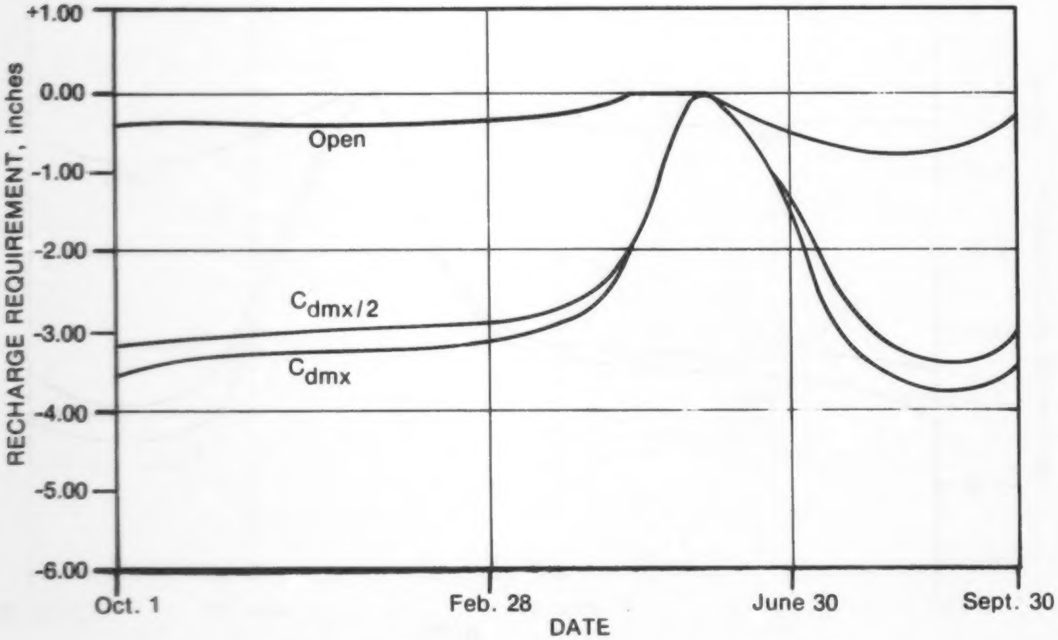


Figure III.87.—Seasonal soil moisture recharge requirements for the Rocky Mountain/Inland Intermountain hydrologic region (4)—intermediate energy aspects.

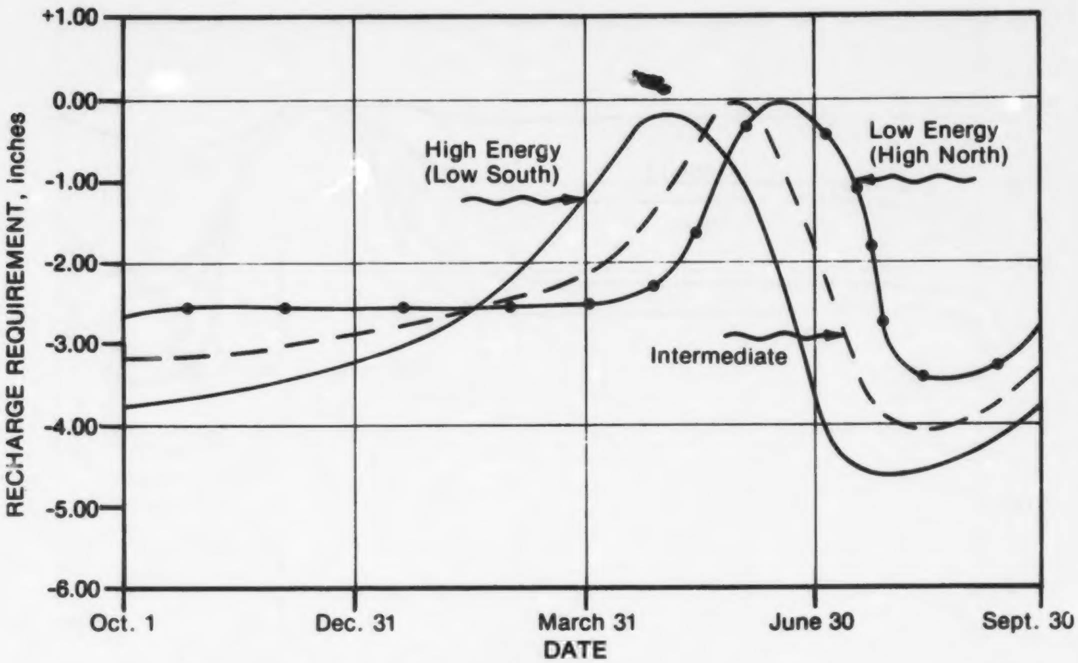


Figure III.88.—Baseline seasonal soil moisture recharge requirements for the Continental/Maritime hydrologic province (6)—all energy aspects.

Changes in soil water status due to silvicultural activities can be estimated from figures III.89 to III.91. Reductions of maximum forest cover density (C_{dmax}) to $C_{dmax}/2$ by selection cutting will not appreciably alter the baseline soil water regime. However, recharge requirements should be decreased uniformly between $C_d = C_{dmax}/2$, and $C_d = 0$. Figures III.89 to III.91 should be used for moderate soils (approximately 3.5 and 5.5 inches field capacity). For deeper soils (approximately 10 inches field capacity), recharge requirements should be multiplied by the following coefficients:

Table III.24.—Soil moisture adjustment coefficients for the Continental/Maritime hydrologic province (6) by aspect/elevation and season

Aspect	Feb. 28	June 30	Sept. 1
High north	1.0	1.0	1.0
Intermediate	1.4	1.2	1.2
Low south	1.7	1.3	1.4

Adjustment coefficients for soils having between 5.5 and 10 inches water holding capacity can be approximated by interpolation.

In the Central Sierra province (7), baseline soil water recharge requirements for conditions of full hydrologic utilization are plotted on figure III.92.

Changes in soil water status due to silvicultural activities can be estimated from figures III.93 to III.95. Reductions of maximum forest cover density (C_{dmax}) to $C_{dmax}/2$ by selection cutting did not appreciably alter the baseline soil water regime. However, recharge requirements should be decreased uniformly between $C_d = C_{dmax}/2$, and $C_d = 0$. Figures III.93 to III.95 should be used for moderate soils (approximately 5.5 inches field capacity). For deeper soils (approximately 10 inches field capacity), recharge requirements in figures III.93 to III.95 should be multiplied by the following coefficients:

Table III.25.—Soil moisture adjustment coefficients for the Central Sierra hydrologic province (7) by aspect/elevation and season

Aspect	March 29	June 27	Oct. 1	Dec. 30
High north	1.1	1.0	1.0	1.0
Intermediate	1.4	1.2	1.2	1.2
Low south	1.0	1.7	1.3	1.4

Adjustment coefficients for soils having between 5.5 and 10 inches water holding capacity can be approximated by interpolation.

In the Northwest hydrologic province (5), baseline soil water requirements for conditions of

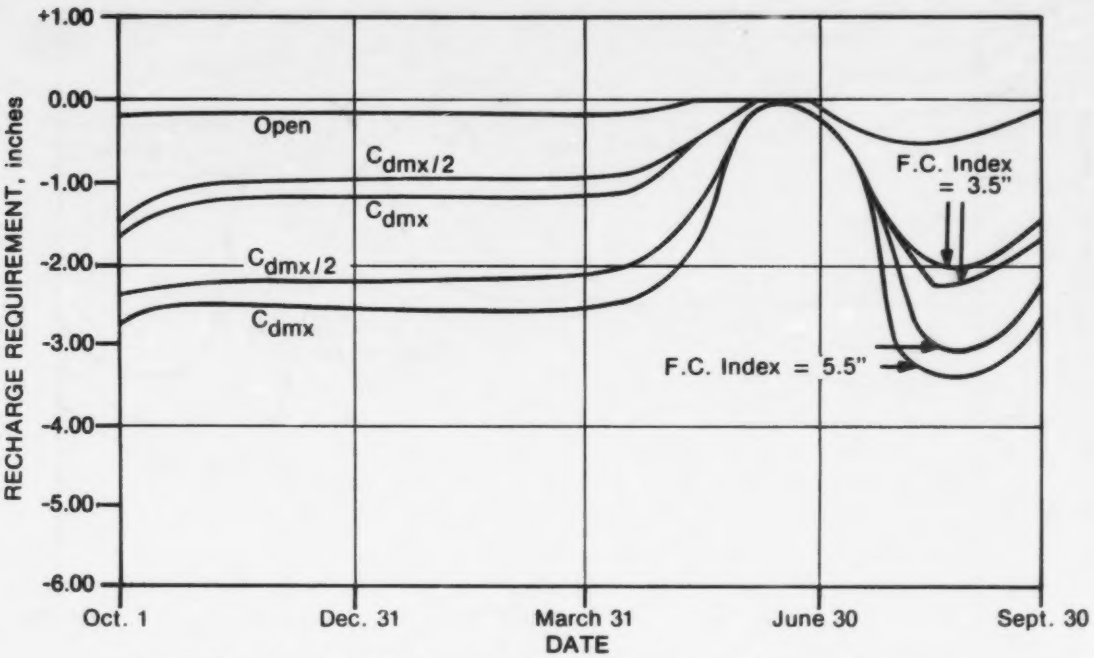


Figure III.89.—Seasonal soil moisture recharge requirements for the Continental/Maritime hydrologic province (6)—low energy aspects.

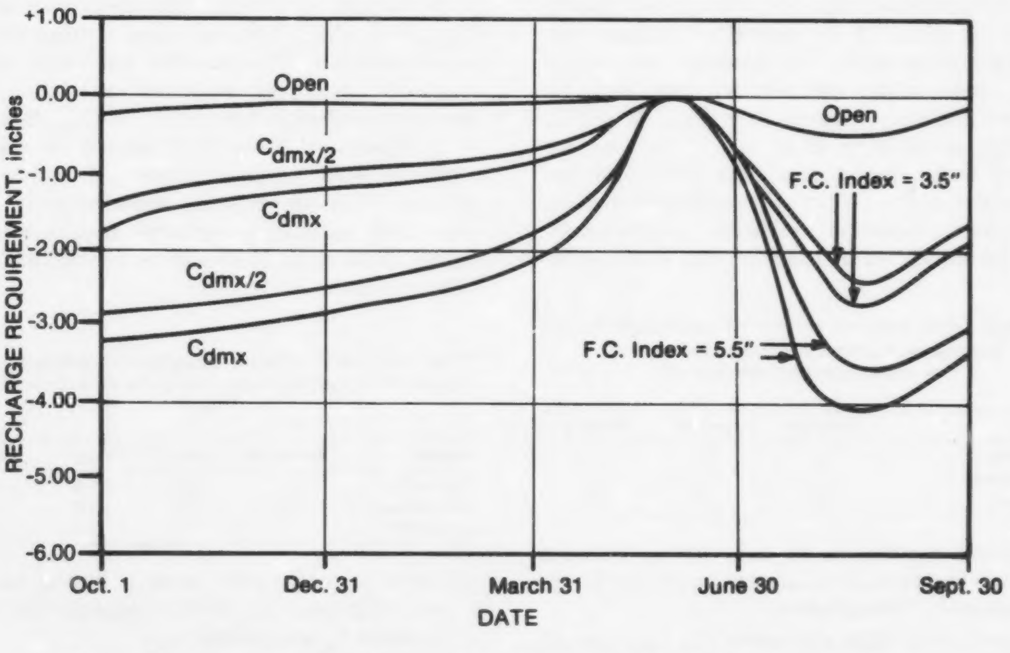


Figure III.90.—Seasonal soil moisture recharge requirements for the Continental/Maritime hydrologic province (6)—intermediate energy aspects.

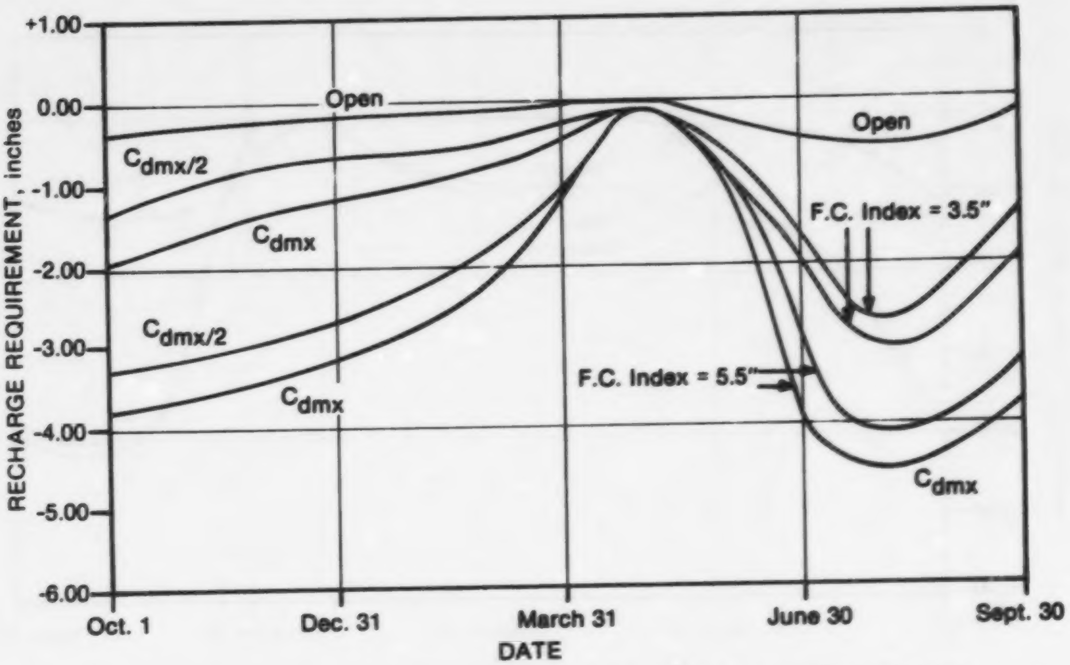


Figure III.91.—Seasonal soil moisture recharge requirements for the Continental/Maritime hydrologic province (6)—high energy aspects.

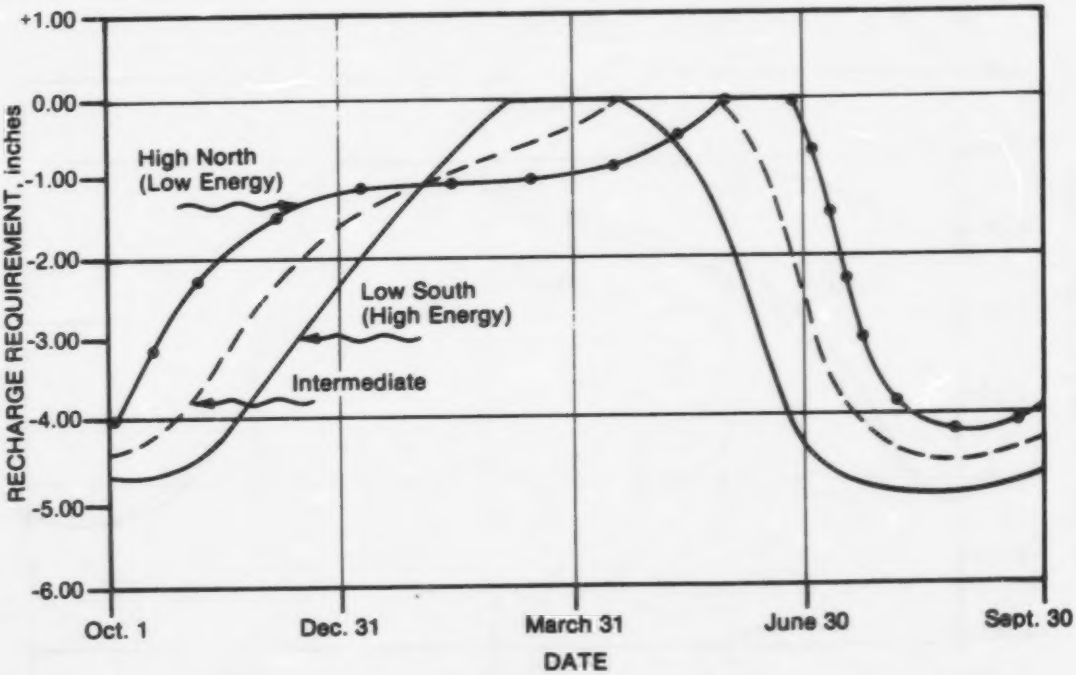


Figure III.92.—Baseline seasonal soil moisture recharge requirements for the Central Sierra hydrologic province (7)—all energy aspects.

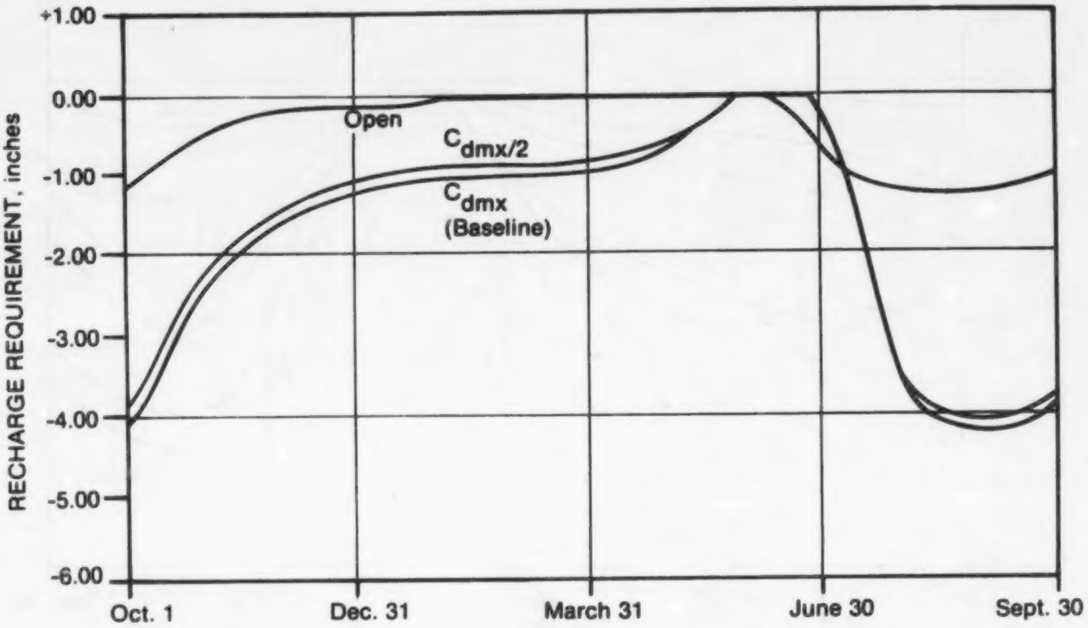


Figure III.93.—Seasonal soil moisture recharge requirements for the Central Sierra hydrologic province (7)—low energy aspects.

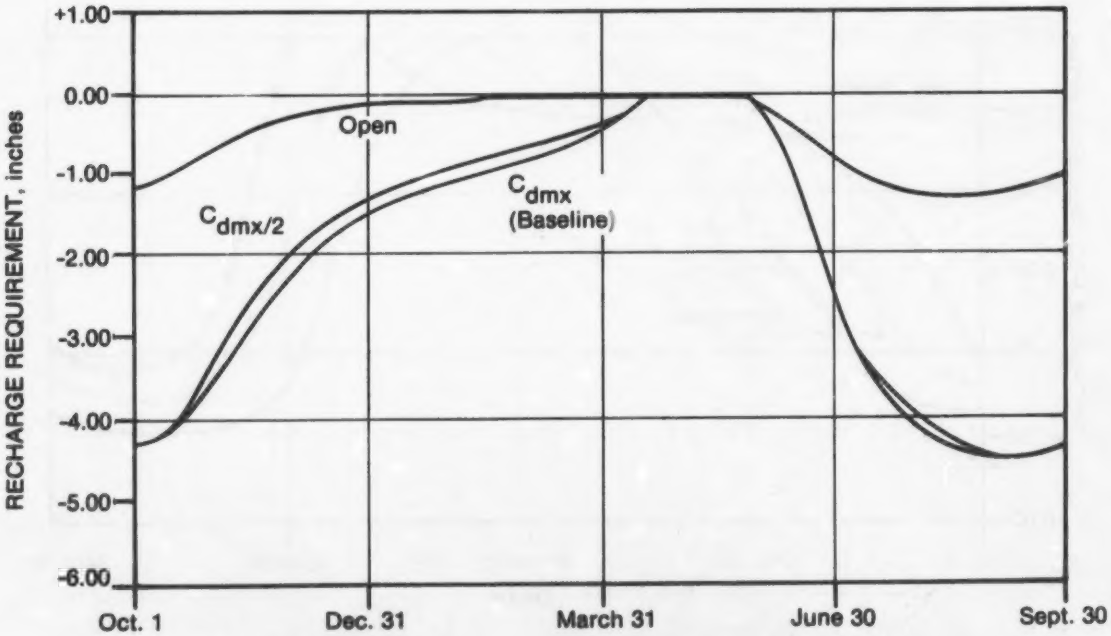


Figure III.94.—Seasonal soil moisture recharge requirements for the Central Sierra hydrologic province (7)—intermediate energy aspects.

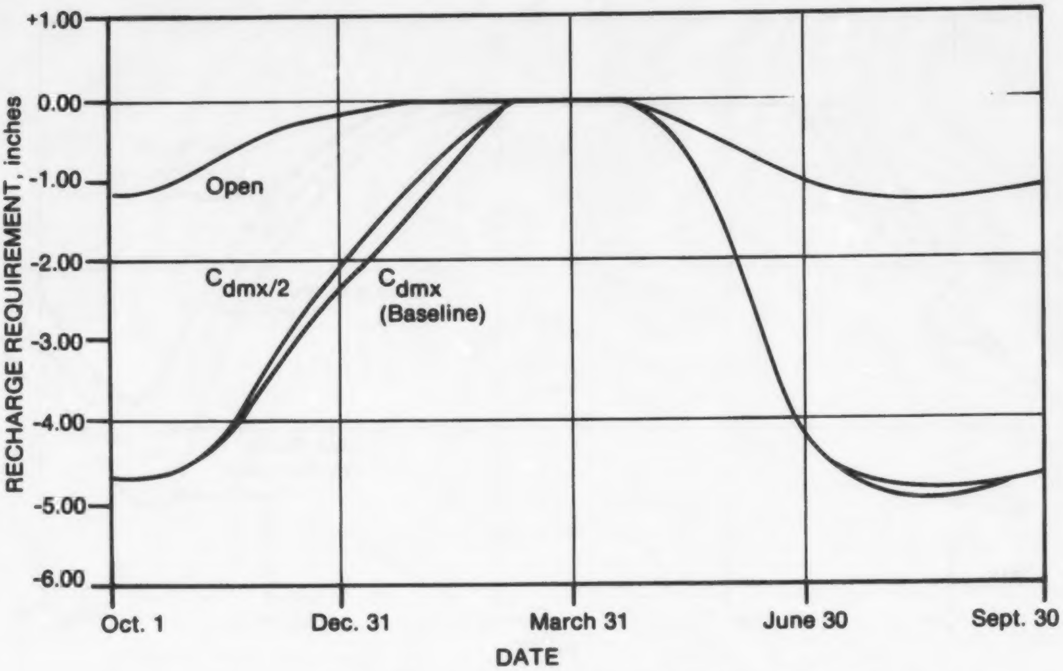


Figure III.95.—Seasonal soil moisture recharge requirements for the Central Sierra hydrologic province (7)—high energy aspects.

full hydrologic utilization are plotted on figure III.96. These curves are proposed for use in the high-elevation coniferous forests where runoff is derived primarily from melting snow.

Changes in soil water status due to silvicultural activities can be estimated from figures III.97 to III.99. Reduction of maximum forest cover density (C_{dmax}) to $C_{dmax}/2$ by selection cutting did not appreciably alter the baseline soil water regime. However, recharge requirements should be decreased uniformly between $C_d = C_{dmax}/2$ and $C_d = 0$. Figures III.97 to III.99 should be used for moderate soils (approximately 5.5 inches field capacity). For deeper soils (approximately 10 inches field capacity), recharge requirements should be multiplied by the following coefficients:

Table III.26.—Soil moisture adjustment coefficients for the Northwest hydrologic province (5) by aspect/elevation and season

Aspect	March 29	June 27	Oct. 1	Dec. 30
High north	1.0	1.8	1.8	1.0
Intermediate	1.0	1.8	1.8	1.0
Low south	1.0	1.8	1.8	1.0

For the New England/Lake States hydrologic region (1), seasonal trends in soil moisture can be shown by a nearly uniform temporal distribution of precipitation during the summer periods. Figure III.100 shows the baseline site specific soil moisture relations. Note that the maximum deficit occurs during the middle of August and is less than 2 inches. This relation generally will not change unless very shallow and/or coarse textured soils are encountered.

Figures III.101 to III.103 present the effects of timber harvesting on soil moisture. No significant differences were noted between the partial cut ($C_{dmax}/2$) and the fully forested condition (C_{dmax}). Reductions in forest cover density of over 50-percent resulted in significant changes in the soil moisture deficit which can be interpolated from figures III.101 to III.103.

The soil moisture deficit patterns discussed were simulated and represent potential deficits, not exact numbers. The relative relationships between cut and uncut seem reasonable and should give a good index to the expected change.

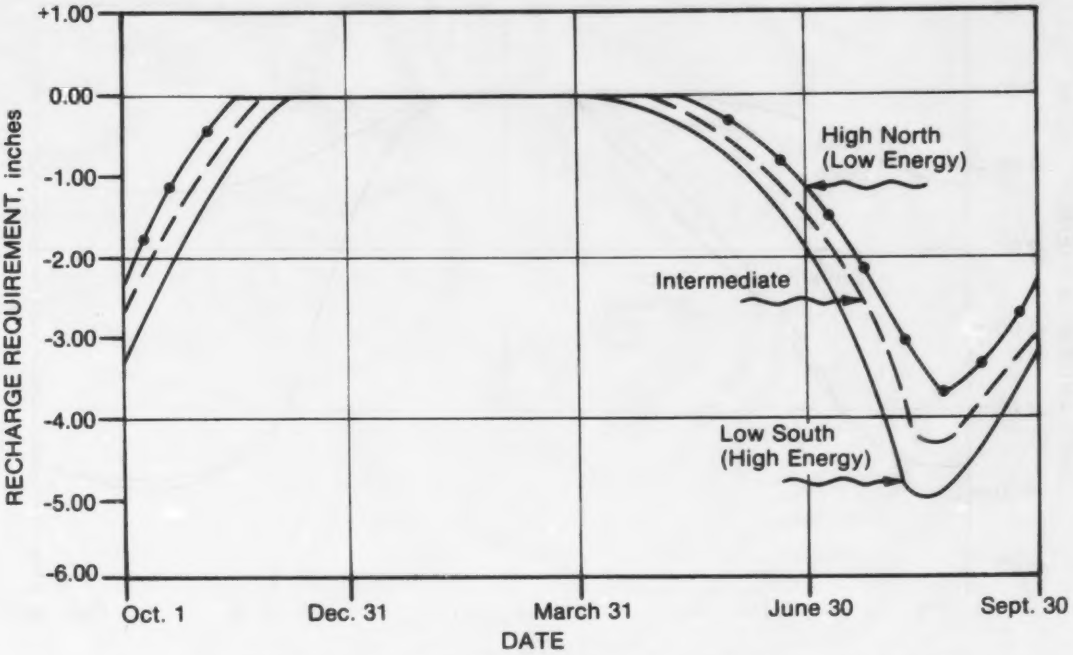


Figure III.96.—Baseline seasonal soil moisture recharge requirements for the Northwest hydrologic province (5)—all energy aspects.

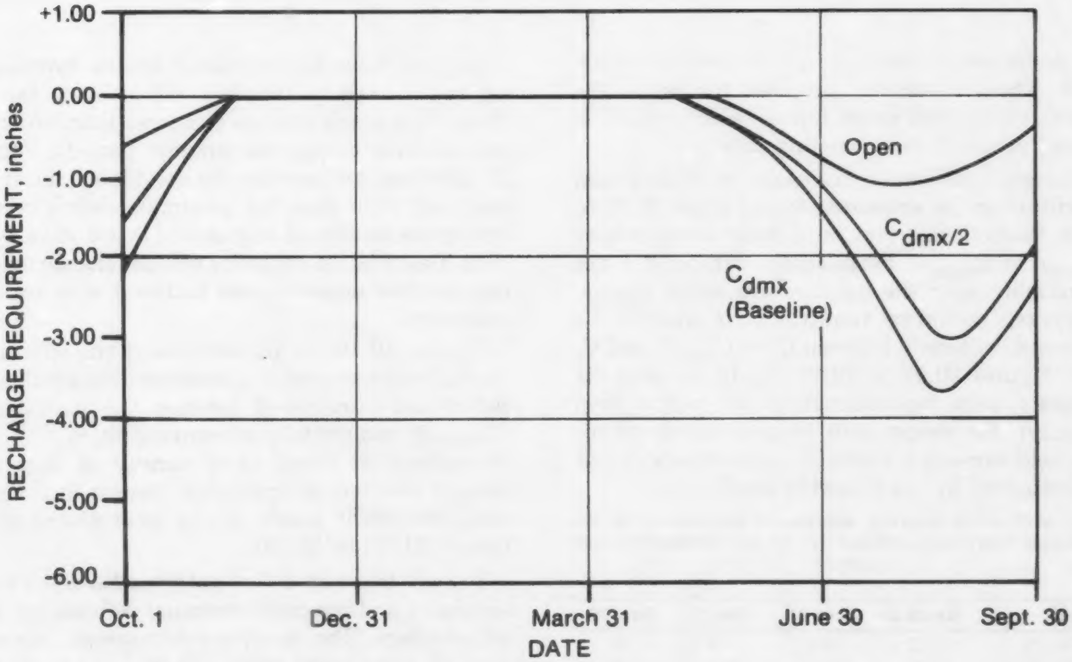


Figure III.97.—Seasonal soil moisture recharge requirements for the Northwest hydrologic province (5)—low energy aspects.

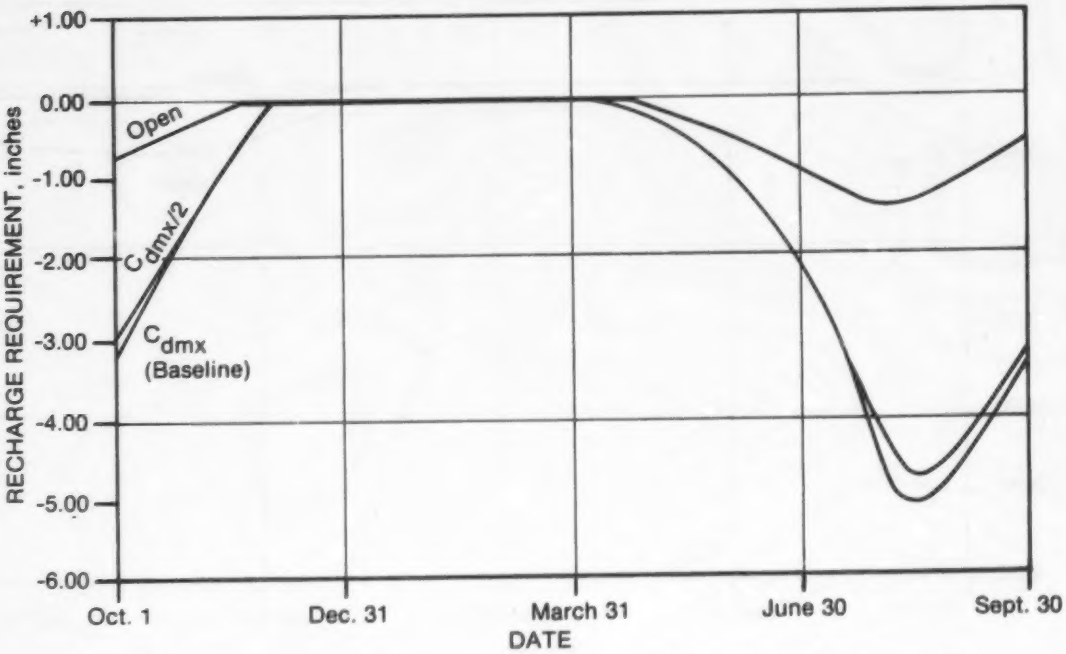


Figure III.98.—Seasonal soil moisture recharge requirements for the Northwest hydrologic province (5)—intermediate energy aspects.

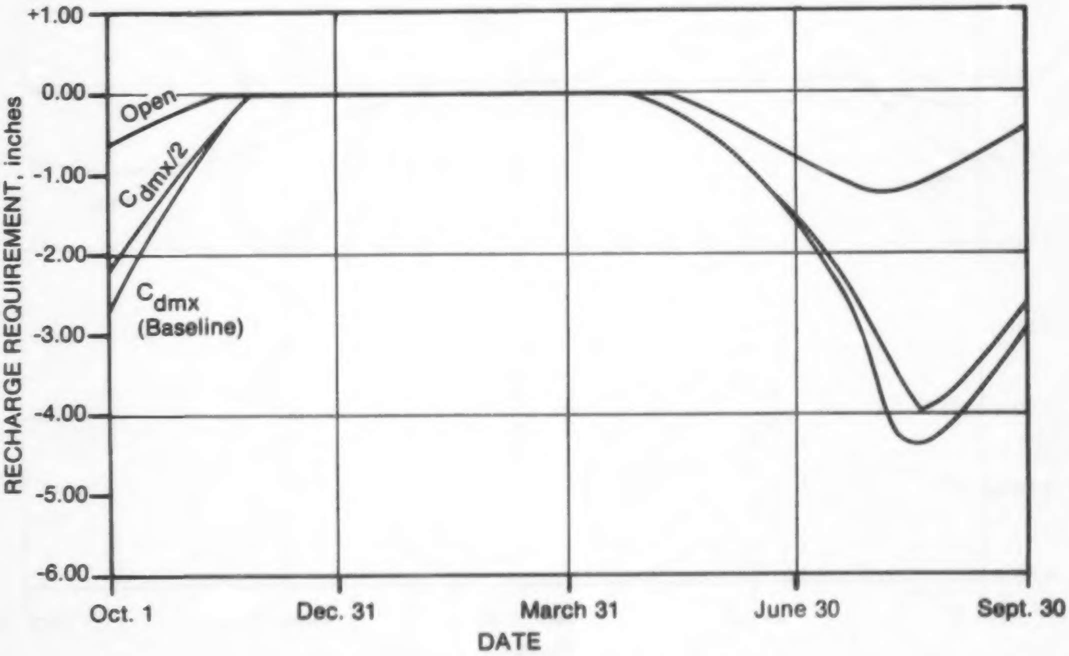


Figure III.99.—Seasonal soil moisture recharge requirements for the Northwest hydrologic province (5)—high energy aspects.

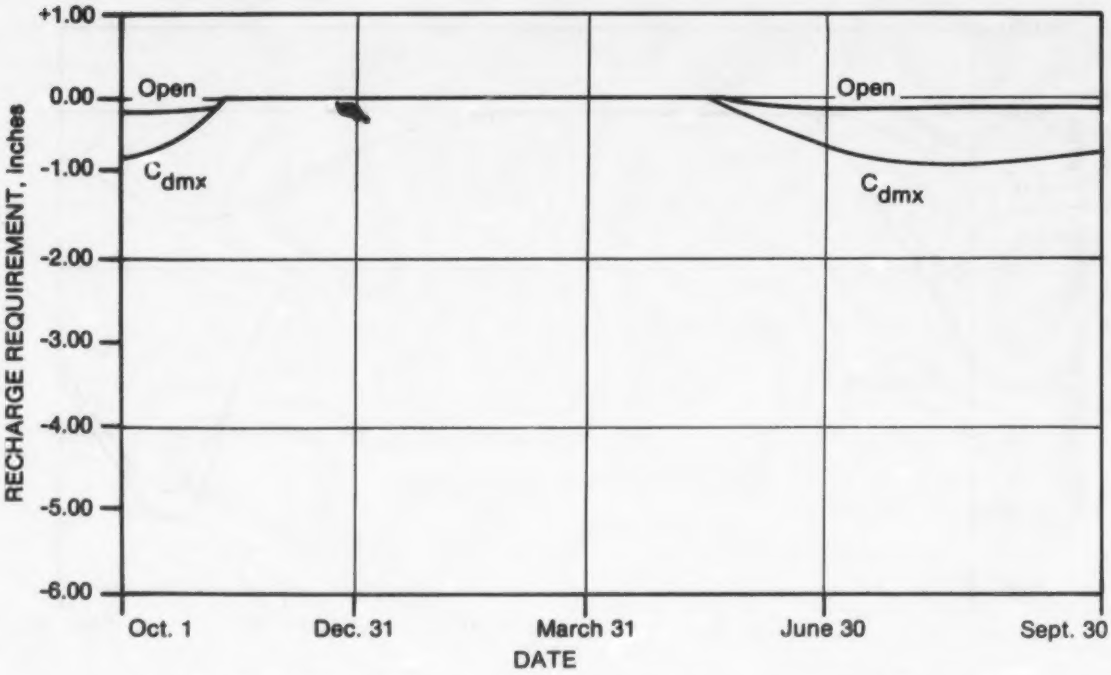


Figure III.100.—Baseline seasonal soil moisture recharge requirements for the New England/Lake States hydrologic region (1)—all energy aspects.

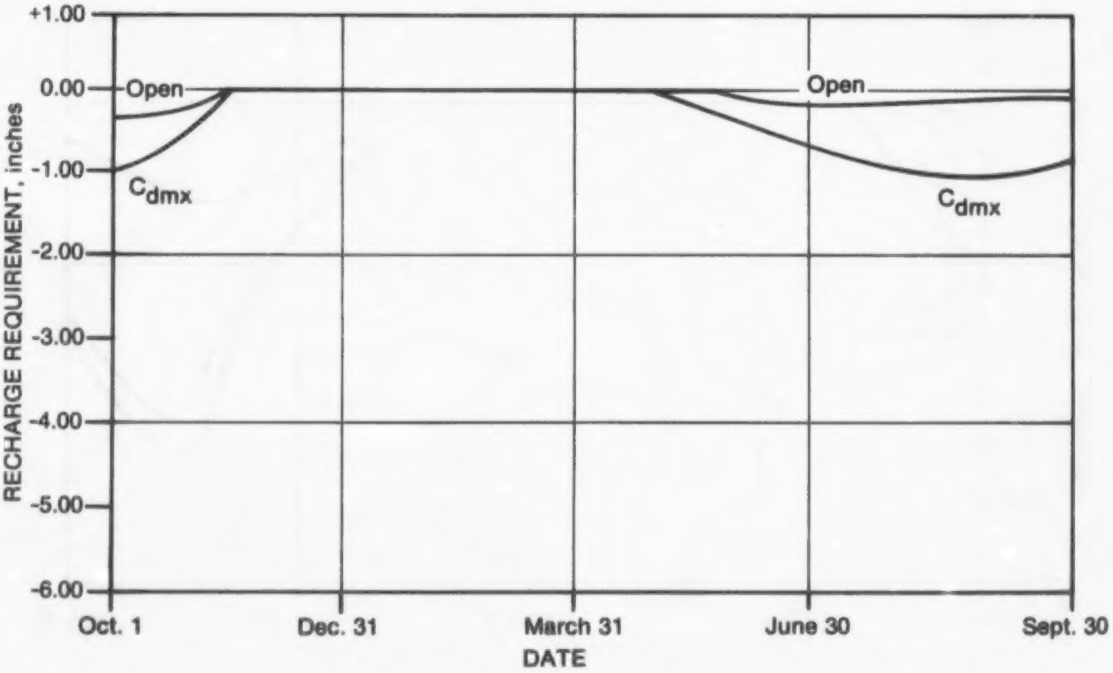


Figure III.101.—Seasonal soil moisture recharge requirements for the New England/Lake states hydrologic region (1)—low energy aspects.

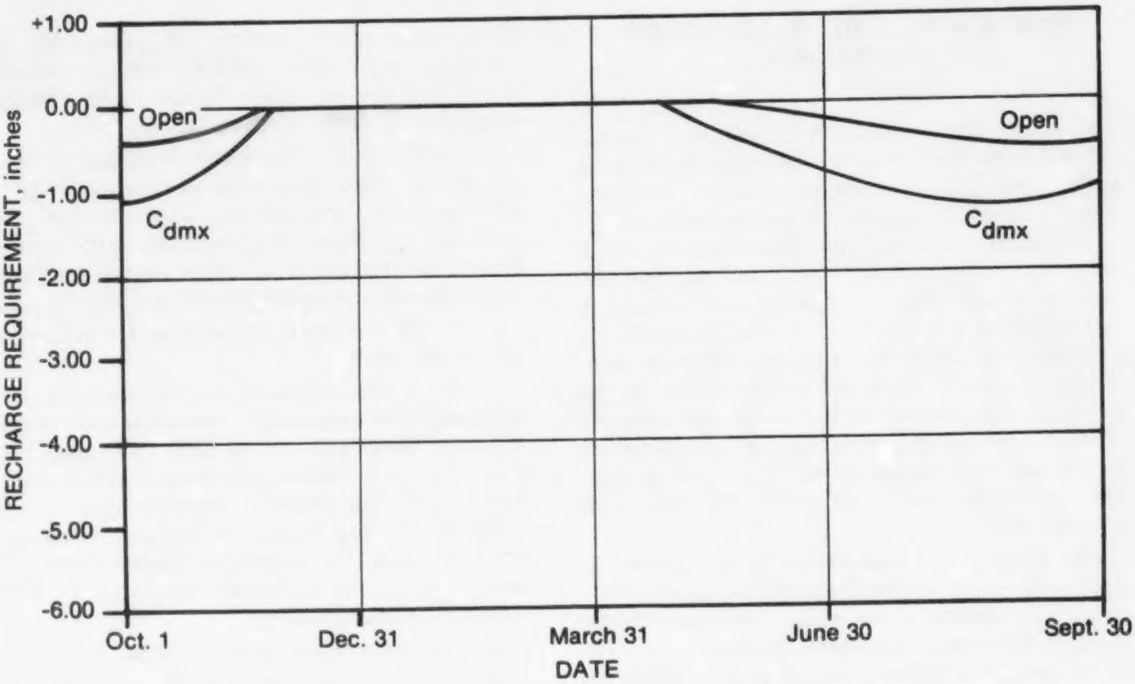


Figure III.102.—Seasonal soil moisture recharge requirements for the New England/Lake States hydrologic region (1)—intermediate energy aspects.

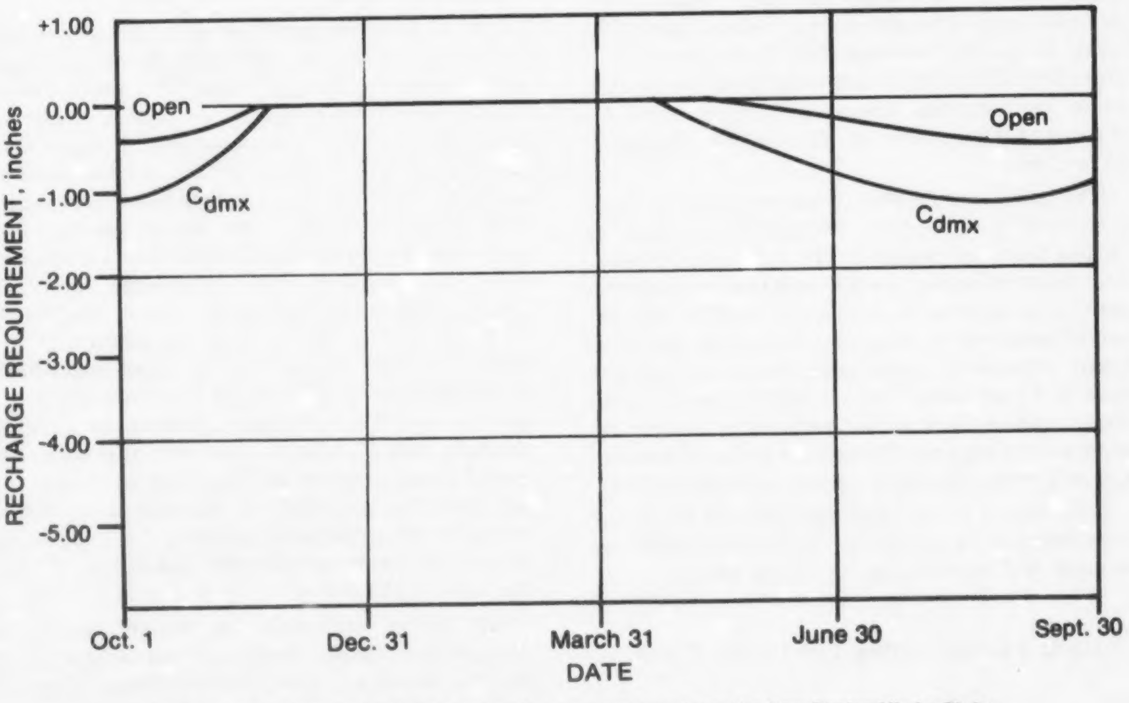


Figure III.103.—Seasonal soil moisture recharge requirements for the New England/Lake States hydrologic region (1)—high energy aspects.

PREDICTING INDIVIDUAL STORM RESPONSES

It is beyond the scope of this handbook to recommend a stormflow prediction technique for specific application. There are too many local techniques, which may be far superior to any generalized approach, to warrant the presentation of a generalized approach. It is recommended that the technique best suited to a specific area be used. A key criterion for selection, however, should be whether or not the technique is sensitive to antecedent conditions. The whole basis for evaluating the effect of silvicultural activities on stormflow is through the changes which occur in antecedent conditions. Any technique not sensitive to antecedent conditions would not reflect the impact of silviculture.

All existing methodologies have significant predictive errors, so the absolute magnitude of the event will contain those errors regardless of the method. However, a reasonable technique sensitive to antecedent conditions should give an adequate estimate of change.

One method, although regional in use, is the R Index method (Hewlett and others 1977), shown to work well in the East. Another method, not process-oriented but sensitive to antecedent conditions, is the SCS method (Soil Conservation Service 1973). Chow (1974) lists several other methods, while McCuen and others (1977) present an annotated bibliography of flood flow frequency techniques.

The point to remember in the stormflow analysis is that the change due to silviculture will equal or be less than the change in the soil water balance. Any time the balance for pre- and post-silvicultural activity conditions is similar, so will be the expected response to individual events. By the same token, response to precipitation events with greater than a 1-year return period will become less affected by treatment as the return period increases. Most events capable of causing significant destruction will be unaffected or at least insignificantly so.

Following is a very brief discussion of the major consideration in predicting individual storm responses and in selecting the design event.

Basis For Evaluating The Design Event

Dealing with individual events within the context of this handbook is a twofold consideration. First, there is the problem of quantifying the magnitude or frequency of the event; and second, estimating the expected change in that design event due to silvicultural activities.

From the outset, it should be noted that there are two levels of flood design; that is, one can design for either major or minor projects. Major implies a risk to human life. Minor implies no risk to life or limb. From the standpoint of silvicultural activities, design events are restricted to minor projects only.

There are two basic approaches for evaluating the design event.

(1) An evaluation can be made of the probability of equalling or exceeding a particular level of flow or design flood. This can be done by performing a flood frequency analysis on a historical flow record for the site. This involves the ranking of various levels of flow and the probability associated with the probability of reoccurrence. Techniques for doing this have been fairly well documented (Water Resources Council 1967).

Two problems arise, however. First, one cannot expect the historical record to be available and, second, if it were available, handbooks or empirical methodologies would not be available for determining the impact that silvicultural activities have on a particular event.

The alternative approach is to determine the hydrologic response expected from a design precipitation or "input" event. This precipitation input could be from rainfall, snowmelt, or rain on snow. In doing this, the assumption is made that the reoccurrence interval for rainfall is the same as the flood event it produces. This is not necessarily true, of course, because the design precipitation event may produce a runoff event with a frequency of occurrence less than or greater than the precipitation event causing it. Larson and Reich (1973) as well as others, however, found that the relationship did average out for small watersheds in Pennsylvania. They found that over the long-term record the average difference in ranking between return period for the precipitation event and the return period for the resulting flow event was zero. The variability in response to successive events on the same basin is largely due to differing antecedent conditions (Hewlett and others 1977) at the time of the storm.

The latter approach, or design based on precipitation, lends itself well to a stormflow analysis consistent with this handbook. The soil moisture distributions presented provide an estimate of antecedent conditions for both pre- and post-silvicultural treatment conditions.

As noted, silvicultural activities require designing for minor projects. Because of the relatively small areas involved and the limited downstream effect of silvicultural activities, the risks from individual events and the changes in them due to silvicultural activities are usually associated with the likelihood of a local, onsite failure (such as exceeding a culvert or bridge capacity, washing out roads or drainage structures, exceeding channel capacities, and other failures due to excessive onsite water).

Selecting The Return Period For The Design Event

Two factors need to be considered in selecting the return period for the design event. The first is the risk of failure that the planner is willing to accept during the life of the project. The second is the expected life of the project or impact. The combination of the acceptable risk of failure and expected life of the project combine to yield the return period for the design storm. Techniques for doing this are defined in Chow (1964), as well as in most other hydrology textbooks.

Usually, the planner can accept a relatively high risk of failure over a relatively short project life. The result is that the concern is usually with the magnitude of the annual, the 5-, or the 10-year event. It must be remembered that the impacts of silvicultural activities on a particular event are really minimal in light of the variability between individual events.

Silvicultural activities can significantly affect frequent events of perhaps less than 1-year return periods. They have minor, if any, effect on the annual event and have an almost insignificant effect on the 5- or 10-year event. Once the antecedent conditions for pre- and post-silvicultural activity conditions are equal, then the potential for a significant response due to activity is eliminated. This would be true whenever the soil moisture modifier coefficients presented earlier are unity.

Selection Of Precipitation Input

Once the appropriate design event has been selected, the precipitation input can be used from onsite data by evaluating the return period; or, it can be obtained from precipitation frequency tables for the region (i.e., USWB 1961).

CONCLUSIONS

The impacts of silvicultural activities upon potential streamflow can be evaluated using procedures for either the snowpack or rainfall regimes; both procedures will give an estimate of the expected change in flow. The form of the output varies depending upon the methodology used. This discrepancy presents little problem, however, since both the distribution graph and the flow duration curve are acceptable, useful means of distributing and interpreting expected potential flow.

Estimates of potential flow (in area-inches) may be converted to average daily discharge (in cubic feet per second) and used in the total potential sediment analysis (ch. VI). The estimate of discharge represents the average discharge for the period of time determined by the duration curve interval or by the dated intervals. In either case, the basic simulation interval upon which all distributions and duration curves are based is either a 6- or 7-day estimate.

Estimations of the potential impacts of a proposed silvicultural activity upon potential streamflow may be determined through use of the procedures presented in this chapter. It is important to combine such analysis with sound professional judgment and interpretation of the estimated impacts according to inherent errors and local conditions. Combining analysis with professional interpretation should result in a reasonable estimate of the potential impacts of management alternatives consistent with the current state-of-the-art in hydrology.

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APPENDIX III.A: EFFECT OF LARGE OPENINGS ON EVAPORATION AND TRANSPORT OF BLOWING SNOW

The technical basis for low snowpack retention in large openings is derived from Tabler's ongoing studies on the evaporation and transport of blowing snow. Tabler surveyed snow accumulation patterns in and around numerous large clearcuts in Wyoming (Tabler 1975). His most recent results, indicating seasonal snow accumulation patterns associated with large open areas (diameters > 15H) (H = height of surrounding trees in feet) are shown in figure III.A.1.[1]

Figure III.A.1 shows a total of four zones that must be analyzed to determine impacts from clearcutting large blocks:

Zone I	—A 5 to 7H lee drift on the windward margin
Zone II	—A wind-exposed scour or fetch area of indeterminate length
Zone III	—A 10H windward drift on the leeward margin
Zone IV	—A drift on the leeward margin whose length is given by the equation:

$$L_{IV} \approx 5H + 3Q/H$$

where:

Q = Total snow transport off the clearcut area (D) in ft³ water equivalent/foot of width normal to the prevailing wind

H = Height of surrounding trees

Tabler has proposed equations for quantifying seasonal snow accumulation in each of the four zones. These equations are summarized in Table III.A.1.

The terms in figure III.A.1 and table III.A.1 are defined as follows:

H = Height of surrounding trees

D = Clearcut diameter in feet (or width in direction of wind)

P_3 = Precipitation water equivalent in feet

ω = A coefficient which indexes the amount of over winter snowpack ablation (perhaps 0.2)

δ = Roughness (slash or regeneration height, etc.) in feet

Q = Total snow transport off the clearcut area (D) in ft³ water equivalent/ft of width normal to the prevailing wind

The total water equivalent transport off the clearcut block in ft³/ft can be computed by the equation:

$$Q = \left[5000/\left(1 + 250\,\frac{1-a}{H}\right)\right]\left[0.87P_3 - 0.2\delta + (0.13P_3 - 0.15\delta)\,a + (0.35\delta - 2P_3/3)\,b - P_3c/3\right] \qquad \text{(III.A.1)}$$

where:

$$a = 0.14^{\frac{10H}{10,000}}$$

$$b = 0.14^{\frac{D-5H}{10,000}}$$

$$c = 0.14^{\frac{D}{10,000}}$$

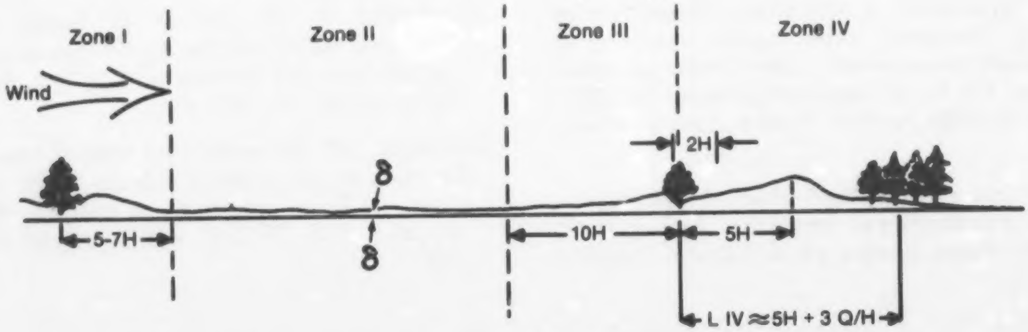

Figure III.A.1.—General pattern of snow accumulation in large clearcut blocks (Tabler 1977).

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[1] Personal communication with Dr. Ronald D. Tabler, Rocky Mountain Forest and Range Experiment Station, Laramie, Wyoming.

Table III.A.1.—Summary of equations for quantifying snow accumulation in large clearcuts (D > 15H)

Zone	Parameter	Equation
I	Drift length	$L_I = 5H$
	Max. snow depth	$D_{MxI} = 3.33\ P_3$
	Precipitation retained	$\rho_I = (2/3)\ P_3$
	Precipitation relocated	$\theta_I = P_3/3$
	Snowpack density	$\gamma_{SI} = .35$
II	Effective length	$L_{II} = D - 15H$
	Max. snow depth	$D_{MxII} = \delta$
	Precipitation retained	$\rho_{II} = 0.35\delta + \omega P_3$
	Precipitation relocated	$\theta_{II} = 0.8P_3 - 0.35\delta$ (assuming $\omega = 0.2$)
	Snowpack density	$\gamma_{SII} = .35$
III	Drift length	$L_{III} \approx 10H$
	Max. snow depth	$D_{MxIII} \approx 0.3D_{MxIV} = 0.35H + 0.20H\log_{10}\left(\frac{Q + P_3L_{IV}}{8.1H^2}\right)$
	Precipitation retained	$\rho_{III} \approx 0.07H + 0.04H\log_{10}\left(\frac{Q + P_3L_{IV}}{8.1H^2}\right)$
	Precipitation relocated	$\theta_{III} \approx P_3 - 0.07H + 0.04H\log_{10}\left(\frac{Q + P_3L_{IV}}{8.1H^2}\right)$
	Snowpack density	$\gamma_{SIII} \approx .40$
IV	Total drift length	$L_{IV} \approx 5H + 3Q/H$
	Max. snow depth	$D_{MxIV} \approx 1.18H + 0.65H\log_{10}\left(\frac{Q + P_3L_{IV}}{8.1H^2}\right)$
	Location of max. depth	$l \approx 5H$
	Deflation distance (fig. III.A.2)	$d \approx 2H$
	Snowpack density	$\gamma_{SIV} \approx .45$

According to Tabler, there is, as yet, no acceptable method for estimating the contribution of Zone III to the total snow transport Q. Reasonable estimates for Q are obtained by assuming no net contribution by Zone III (neither + nor −), leaving a simplified version of equation III.A.1:

$$Q \approx 5000\ [(P_3 - .35\delta)\ (a - b) + (P_3/3)\ (b - c)]$$

Ignoring over-winter *in-situ* ablation ($\omega = 0.0$) and where terms are defined as above, if ω were included,

$$Q \approx 5000\ [(P_3 - \omega P_3 - .35\delta)\ (a - b) + (1/3)\ (P_3 - \omega P_3)\ (b - c)]$$

Evaporation losses are computed from the equation:

$$Q_{loss} = P_3D - 1.53Q - 4.67P_3H - 0.35\delta D + 3.25\delta H \qquad \text{(III.A.2)}$$

Equation III.A.2 can be changed in accordance with the suggested revision of III.A.1, or (assuming $\omega = 0.0$):

$$Q_{loss} \approx P_3(D - 10H) - Q - .35\delta\ (D - 15H) - 10P_3H/3 \qquad \text{(III.A.3)}$$

Figures III.A.2 through III.A.5 by Tabler graphically show the effects of large clearcuts in Wyoming. Undesirable impacts include not only reduced snow accumulation, but also damage to the residual forest from wind and excessive snow accumulation in Zone IV.

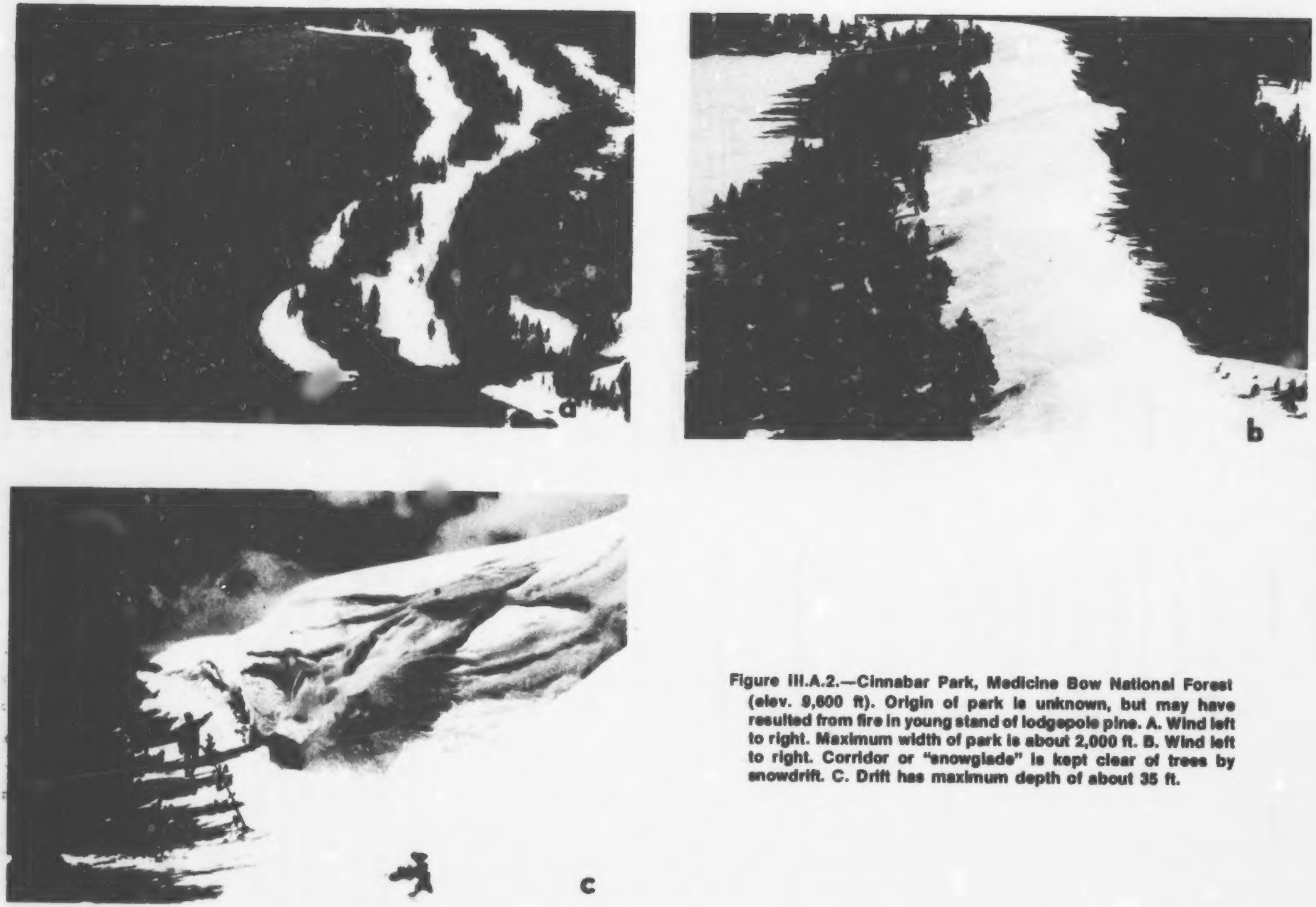

Figure III.A.2.—Cinnabar Park, Medicine Bow National Forest (elev. 9,600 ft). Origin of park is unknown, but may have resulted from fire in young stand of lodgepole pine. A. Wind left to right. Maximum width of park is about 2,000 ft. B. Wind left to right. Corridor or "snowglade" is kept clear of trees by snowdrift. C. Drift has maximum depth of about 35 ft.

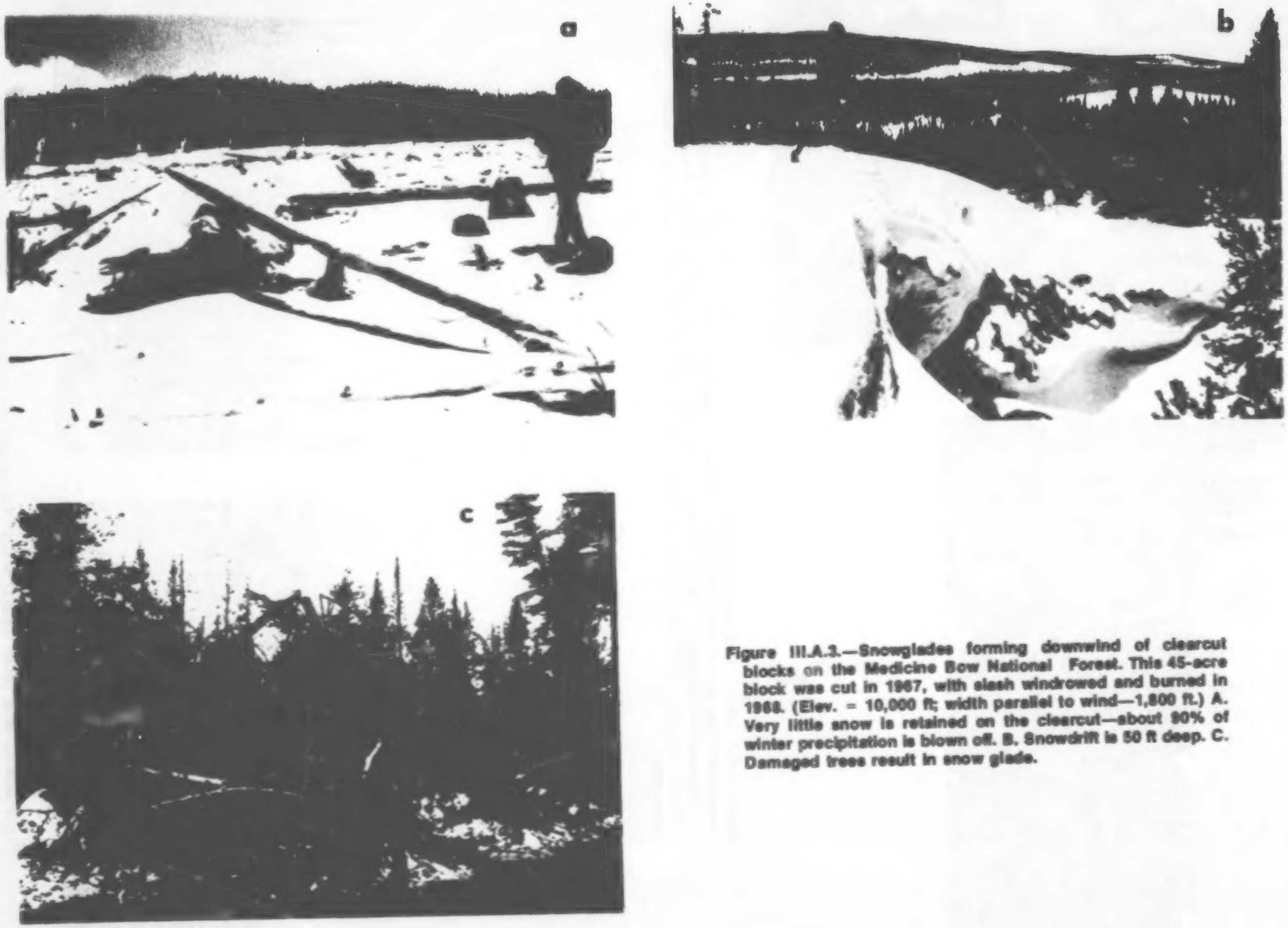

Figure III.A.3.—Snowglades forming downwind of clearcut blocks on the Medicine Bow National Forest. This 45-acre block was cut in 1967, with slash windrowed and burned in 1968. (Elev. = 10,000 ft; width parallel to wind—1,800 ft.) A. Very little snow is retained on the clearcut—about 90% of winter precipitation is blown off. B. Snowdrift is 50 ft deep. C. Damaged trees result in snow glade.

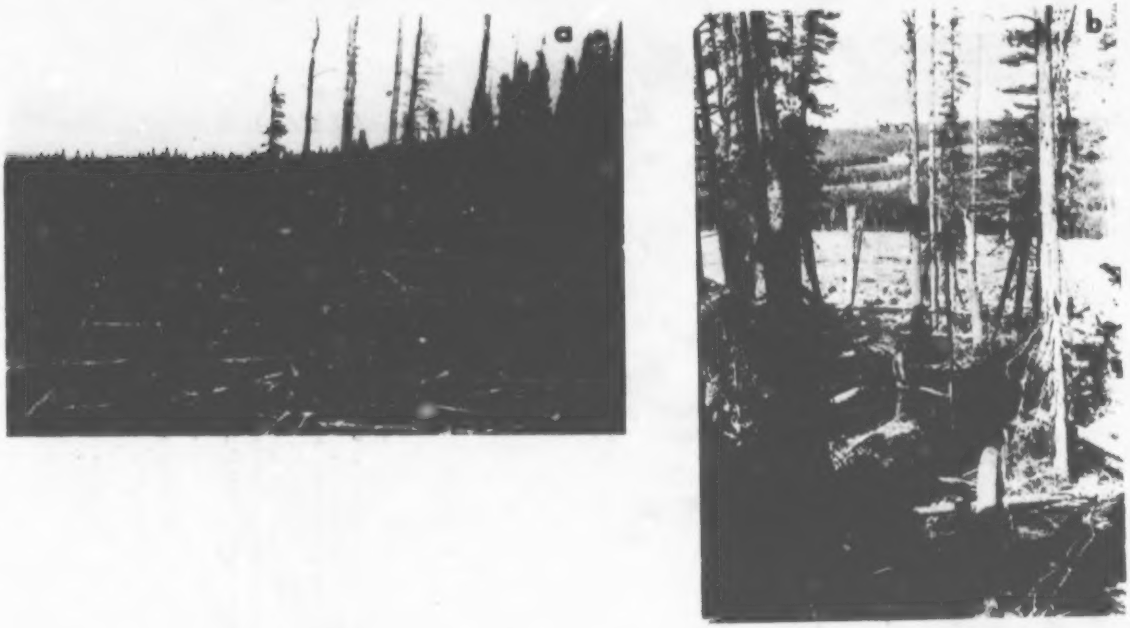

Figure III.A.4.—Residual timber on downwind side of clearcut shown in fig. III.A.3. Late-lying snowdrift keeps soil saturated throughout summer, making trees more vulnerable to windthrow. A. Windfall was salvaged in 1974 in a strip 100 to 200 ft wide on downwind side of block. B. Windfall between clearcut and glade accumulated since 1974 salvage. This view looks directly into wind.

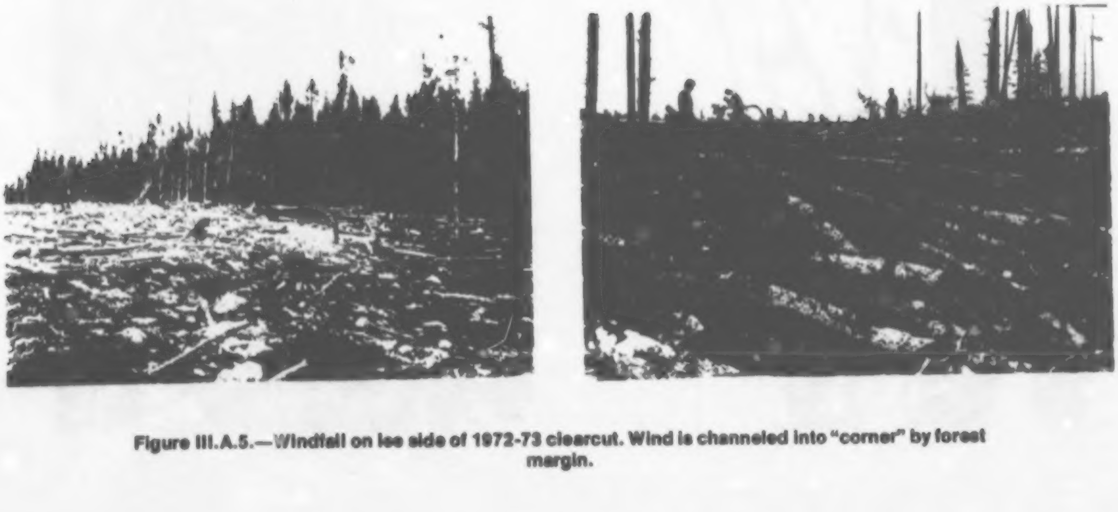

Figure III.A.5.—Windfall on lee side of 1972-73 clearcut. Wind is channeled into "corner" by forest margin.

APPENDIX III.B: HYDROLOGIC MODELING

PHILOSOPHY

Because of lack of sufficient data from experimental watersheds and the resulting inability to characterize universal process response from the experimental data available, process simulation has been chosen as the basis for quantifying the hydrologic impact. "Process" quickly became a keyword in this effort and led to an important decision in the modeling effort — that physically based process models were to be used wherever possible rather than probalistic or stochastic models. Existing physically based mathematical models were evaluated as part of an earlier Forest Service/EPA contract EPA-600/3-77-078.

Mathematical modeling, or the objective analysis of the information-feedback characteristics of hydrologic systems, provides criteria for estimating system hydrology, since system structure, delay, and amplification are taken into consideration. This modeling process requires six basic steps as summarized by Jones and Leaf (1975):

(1) Construction of a dynamic mathematical model in which important interactions between system components are defined.

(2) Programming and execution of the model over a period of time on a digital computer.

(3) Comparison of model results against all pertinent available data. (The regional approach can be effectively used for model validation.)

(4) Revision (tuning) of the model until it is acceptable as a representation of the actual system.

(5) Alteration of certain model components in order to represent changes in the real system.

(6) Repeat of step 3 to verify the "tuning" and/or model alteration.

At each step in the above sequence, the previous steps often need to be revised. The whole procedure is not unlike the development of an aircraft or automobile, where repeated design changes and testing ultimately result in an operational prototype.

However, all models are, in one way or another, imperfect and simplified representations of reality; there are limitations in the modeling approach. Accuracy and validity of any model is not absolute and has a meaning only relative to some prescribed use. Consequently, subjective judgment is necessary in selection, use and application; error is inherent in both the judgment made and the result obtained. Errors in simulation may appear great, but, given the present state-of-the-art, there is no other way of quantifying a universal response which can be interpolated to site specific applications.

Bear in mind that the danger in any quantitative model-validation procedure is that it takes on an "aura of authenticity" and may lead the inexperienced modeler to forget the underlying subjective assumptions. Primary confidence in modeling must depend on: (1) how acceptable or plausible the model is in describing natural processes, and (2) the reasonable assumption that "if all the necessary components are adequately described and properly interrelated, the model system cannot do other than behave as it should" (Forrester 1969). Because much of the content of complex natural system models is derived from nonquantitative sources, the defense of such models ultimately must rest in careful subjective evaluation of their performance by experienced professionals who are familiar with these systems.

In practice, the utility of a model lies in its ability to precisely represent overall behavior of natural systems and system response to changes in one or more system components.

SELECTION OF THE MODELS USED

Several criteria were used in selecting appropriate models.

An examination and evaluation were completed on the structure of the models themselves, the parameters used, and the means by which parameters were estimated. Models that were process-oriented were isolated; those that optimized parameter estimates to the point where they no longer represented real-world inputs were eliminated. In addition, those models having inherent feedback to the calibration phase which, much like optimizing, detracted from true process response were also eliminated. Adequate documentation, referenced applications, and contact with experienced users were relied upon heavily. Selected models were process-oriented and did not violate assumptions when in use. Finally, models were selected according to the level of expertise, the time frame, and the data base available.

After model selection, the second phase involved testing and fitting the selected models to representative and experimental watersheds, evaluating their range of applicability, and evaluating their performance with respect to known responses.

The EPA/FS Phase I study (1976) reviewed several models developed for forest hydrology. They varied widely in terms of complexity and scope, depending on their application. Most were based on a practical engineering approach which achieved a balance between theory, available data, and operational objectives and constraints. The successful application of each model depended to some extent on empirical derivations of several parameters and relationships, some of which were unique to geographic areas.

Based on all the criteria and assumptions mentioned, two models were selected as the most readily useful: The Subalpine Water Balance Model (WATBAL) developed by Leaf and Brink (1973b) and PROSPER (Goldstein and others 1974).

Other models may have been equally suited, however, the two selected models best fit the requirements of this handbook. It should be emphasized that it was not an object of the selection process to promote any specific model.

GENERAL PRINCIPLES FOR APPLICATION AND USE OF MODELS

Subalpine Water Balance Model Description

The Subalpine Water Balance Model (WATBAL) was chosen because it had previously been developed according to the above mentioned concepts and because it was calibrated for the high-elevation snowpack subalpine zones. This dynamic hydrologic model was developed by the U.S. Forest Service, and was specifically designed to simulate the hydrologic impacts of watershed management on snow pack (Leaf and Brink 1973b and 1975). Figure III.B.1 is a flow chart of the basic model. Documentation for application of this model can be found in appendix III.C.

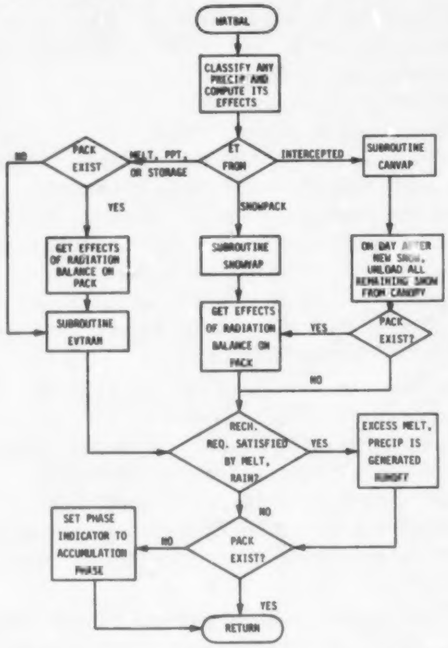
WATBAL
CLASSIFY ANY PRECIP AND COMPUTE ITS EFFECTS
NO
PACK EXIST
MELT, PPT, OR STORAGE
ET FROM
INTERCEPTED
SUBROUTINE CANVAP
YES
SNOWPACK
GET EFFECTS OF RADIATION BALANCE ON PACK
SUBROUTINE SNOWMAP
ON DAY AFTER NEW SNOW, UNLOAD ALL REMAINING SNOW FROM CANOPY
SUBROUTINE EVTRAN
GET EFFECTS OF RADIATION BALANCE ON PACK
YES
PACK EXIST?
NO
RECH. REQ. SATISFIED BY MELT, RAIN?
YES
EXCESS MELT, PRECIP IS GENERATED RUNOFF
NO
SET PHASE INDICATOR TO ACCUMULATION PHASE
NO
PACK EXIST?
YES
RETURN

Figure III.B.1.—General flow chart of Subalpine Water Balance Model (from Leaf and Brink 1973b). WATBAL model.

WATBAL models: (1) winter snow accumulation, (2) the energy balance, (3) snowpack condition, and (4) resultant melt in time and space under a variety of conditions. Combinations of aspect, slope, elevation, and forest cover composition and density are included. Much of the snowmelt portion of the computer program was initially written by the Watershed Systems Development Unit at the Pacific Southwest Forest and Range Experiment Station (Willen and others 1971). With this snowmelt model, the probable effects of forest cover manipulation have been simulated.

The model consists of three parts: (1) the determination of the form of precipitation (rain or snow), (2) snowpack condition in terms of energy level and free water requirements, and (3) the melting process. Shortwave and longwave radiation reaching the pack is estimated by means of a transmissivity coefficient function, which depends on the density and composition of the forest cover.

Radiation inputs are adjusted for slope and aspect. Reflectivity of the snowpack is varied according to precipitation, the energy balance, and time.

The snowpack is assumed to behave as a dynamic heat reservoir; thus all elements in the snowmelt portion of the model are expressed in units of heat. The net external energy balance is computed at the snow surface. Rain and snow are converted from inches at the prevailing air temperature to equivalent gram-calories. Each precipitation event is added algebraically as a caloric-heat event to develop the heat reservoir or snowpack. Temperatures within the snowpack are computed using unsteady heat flow theory. The snowpack will yield melt water only when it has reached a zero energy deficit (snowpack temperature = 0°C) and its free water holding capacity is satisfied. Snowmelt rates after the pack is primed are governed primarily by the longwave and shortwave energy balances at the snow surface.

Input Requirements For WATBAL

Data requirements for the Subalpine Water Balance Model (WATBAL) are conventional. Information, routinely available from such agencies as the Soil Conservation Service, NASA, Forest Service, Geological Survey, and National Weather Service, is adequate for most applications. The data requirements can be ranked in three categories as follow:

1. **Watershed characteristics**
    a. USGS topographic maps
    b. USFS vegetation type maps
    c. SCS soil survey data
2. **Snowpack and snow cover extent**
    a. Conventional SCS snowcourse network
    b. SCS SNOTEL network
    c. NASA LANDSAT, etc.
3. **Climatological data**
    a. Daily maximum and minimum temperatures
    b. Daily precipitation

The density of the available observation networks will vary; however, as a rule of thumb, it can be assumed that the snowcourse systems such as SNOTEL will be adequate. Moreover, the density of the National Weather Service Climatological Data network in the subalpine zone also appears adequate for most purposes.

PROSPER Model

PROSPER is an atmosphere-soil-plant water flow model that has been well documented (Goldstein and Manken 1972, Goldstein and others 1974) and recently evaluated in the southern Appalachians (Swift and others 1975). A schematic of PROSPER is shown in figure III.B.2. The version used has been operational on a daily basis, and a description of the computational procedures for each day follows (from Goldstein and others 1974):

(1) Precipitation for the day enters the system. If there is no precipitation, the simulation proceeds to step 2. Precipitation initially enters the interception storage compartment which has a maximum storage capacity as a function of leaf area index. When the interception compartment is full, any additional precipitation becomes throughfall.

(2) If the intercept storage compartment does not contain any water, i.e., if $\theta_0 = 0$, then the simulation proceeds to step 3.

If $\theta_0 > 0$, then $F_v(r_x = 0)$ is calculated. Since r_a is the only resistance to evaporation of intercepted water, r_x is set to zero. If $\Theta_0 \geq F_v(r_x = 0)$, then an amount of water equal to $F_v(r_x = 0)$ is evaporated from the interception storage compartment, F_w is set to zero, and the simulation proceeds to step 3. If $F_v(r_x = 0) > \Theta_0$ then all of Θ_0 is evaporated and an amount of energy equal to $L_v \Theta_0$ (where L_v is the latent heat of vaporization for water) is subtracted from the total net radiation for the day, R_N. The adjusted value of R_N will be used instead of the total net radiation in step 3.

(3) At this point, the simulation enters a loop to calculate soil water transferred to the atmosphere by evapotranspiration and soil water redistribution and drainage. In the original implementation of PROSPER (Goldstein and Mankin 1972a), the looping structure was not incorporated into the computer program. The saturated soil water conductivities used in the original implementation were based on data for agricultural soils (Miller and Klute 1967). For these values (on the order of 1 cm/day) a single calculation of soil water movement in a day using total daily throughfall and solar radiation was

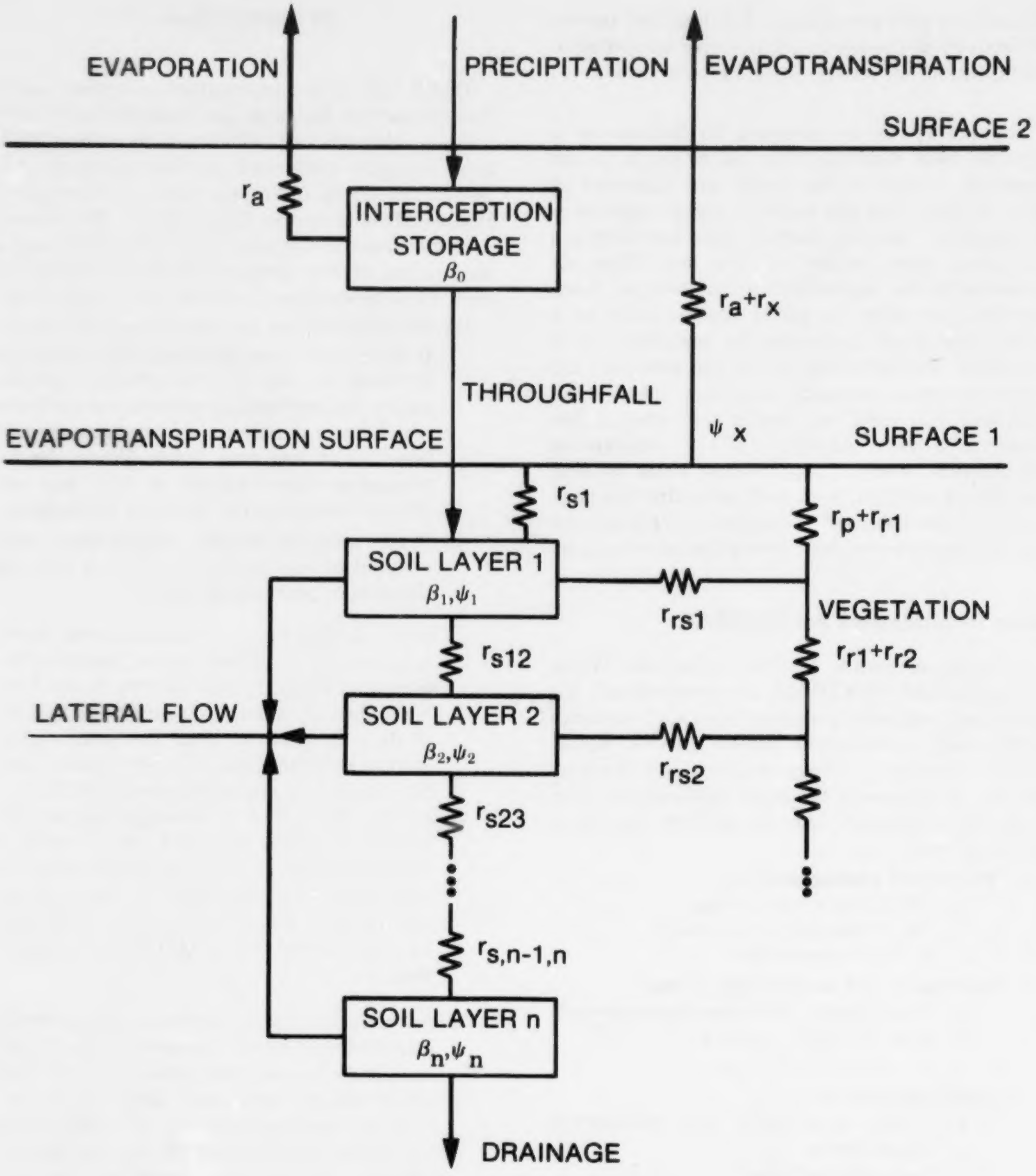

Figure III.B.2.—Schematic of PROSPER (from Goldstein and others 1974).

adequate. However, saturated soil water conductivities have been found to be two to three orders of magnitude greater for forest soils than for agricultural soils (Freeland 1956, Longwell and others 1963, Peters and others 1969). For these high values of soil water conductivity, single daily calculations produce numerical instabilities. This necessitates the inclusion of the loop structure which makes N iterations in calculating the daily water movement. The number of passes through the loop, N, is dependent upon throughfall, layer thickness, maximum saturated soil water conductivity, and N for the previous day.

(4) Upon entering the loop, soil water potentials, conductivities and resistances are calculated for the soil layers. One Nth of the daily throughfall and net radiation are used to calculate F_V $[f_x = g_1(\Theta_x)]$ by the procedure outlined in the previous section, unless $F_x = F_V$ $[r_x = g_1(\Theta_x)]$ has been set to zero in step 2, in which case the depletion of soil water by evapotranspiration is zero. Also calculated are Θ_x and Θ_i for all i. The volumetric soil moisture content of each level, Θ_x, is readjusted by Θ_i. If the moisture in any level exceeds saturation, the excess is removed by lateral flow. The amount of water in the bottom layer exceeding field capacity drains at a rate equal to the hydraulic conductivity.

(5) If the program has not passed through the loop N times at this point, the simulation returns to step 3 and goes through the loop again. If the simulation has gone through the loop N times, then the daily total of evapotranspiration, lateral flow from each soil layer, and drainage are calculated by summing the amounts calculated in each of the N passes through the loop.

(6) The simulation proceeds to the next day and returns to step 1.

Input Requirements For PROSPER

In general, daily precipitation, solar radiation, temperature, vapor pressure, and average wind speed are the climatic inputs. Vegetative inputs include the number of days from January 1 until the vegetation is 50 percent leafed out and the number of days from January 1 until 50 percent of the leaves are off. An estimated, maximum (summer) and minimum (winter), interception storage is also needed, as are estimates of the leaf area index in both summer and winter. Input requirements for soil properties consist of moisture release curve data for the upper two soil horizons (i.e., rooting zone) and field capacity estimates for the other three lower horizons. Also needed for input are the saturated conductivity of the upper two horizons and the moisture release-conductivity curves which are generated internally using the techniques of Millington and Quirk (1959) via the Green and Corey (1971) program. Initial soil moisture contents as well as field capacities for each of the five layers are also needed.

Other parameters and coefficients are needed to describe energy transfer rates and these were taken from the PROSPER sensitivity analysis by Luxmoore and others (1976) as there was little basis or expertise for modifying them.

One constraint exists in the use of the PROSPER model: The leaf area index-ET relationships were developed for conditions that existed at Coweeta Hydrologic Laboratory in North Carolina. Although the universality of this function has not been previously established, the model did perform well when used elsewhere.

Model Output

By definition, neither PROSPER or WATBAL are streamflow simulation models. PROSPER is basically an evapotranspiration model with no subsurface routing components. WATBAL is a snowmelt model and, like PROSPER, has no subsurface routing. Neither model is capable of delivering water to a stream channel. The lateral outflow and drainage simulated by these models represents water which is on site and potentially available for streamflow and may or may not represent routed streamflow.

The two models were each used for different climatic regimes and there were differences in modeling objectives and interpretation of each. PROSPER was used primarily in humid, nonsnowpack areas; the rationale was to first simulate evapotranspirational loss and then compare seasonal and annual outflow with observed outflow. This comparison was usually acceptable. Again the outflow simulated represented unrouted water excess. However, the agreement between this excess and observed streamflow improved as a function of basin storage. Those shallow-soiled basins with short resonance times or short "times of concentration" had a fairly good correlation between simulated excess water and observed flow.

Deep-soiled, slow responding watersheds like Coweeta had poor correlations.

WATBAL was used primarily in regions where significant snow packs develop, and where there was need for a snowmelt routine. The same problem of routing exists in WATBAL that exists in PROSPER. However, the actual hydrograph from the basins where WATBAL was used is dominated by a seasonal snowpack and melt runoff. This flow is more predictable, more concentrated, and the translation of melt to streamflow is more direct. As a result, in those hydrographs which are snowmelt-derived, there is more direct correlation between simulated excess water and actual streamflow. It was possible to present this simulated flow as a time-serial hydrograph. For those simulations that were rainfall driven, the timing of "simulated flows" was distorted and delayed. It was unacceptable to present these values as streamflow in any serial presentation.

Since the magnitudes of simulated flow and observed flow using PROSPER had similar frequency distributions, the simulated outflow could be presented in a frequency distribution (not time dependent) as a representation of actual flow.

Again, both models adequately simulate the evapotranspiration losses, and the simulated outflow is presented as water potentially available for streamflow. No existing model actually simulates an unbiased acceptable estimate of streamflow. Existing models must be acceptable until better models are developed.

In order to simulate treatment effect, after the models were calibrated cover density parameters affecting the intercepting and transpiring surfaces were modified to estimate the response due to treatment.

APPENDIX III. C: CALIBRATION OF SUBALPINE WATER BALANCE MODEL

The Subalpine Water Balance Model (Leaf and Brink 1973b) was developed for, and has been successfully applied to a number of representative watersheds throughout the Rocky Mountain region. For lack of a better tool, this model was also used to simulate the snow pack hydrology of representative watersheds in each hydrologic region. This section illustrates application of the model to a number of index watersheds.

INDEX WATERSHEDS

Each index watershed was divided into several hydrologic subunits that vary according to slope, elevation, aspect, and forest cover. The water balance was simulated on each subunit; area-weighted responses were computed and summed to obtain the overall response for the entire basin. Both time and spatial variations were thus taken into account.

Daily temperature extremes in each of the subunits were estimated by extrapolating published temperatures at nearby base stations, generally cooperative stations operated by the National Weather Service. Because reliable long-term radiation data were not available for most areas, shortwave radiation input to the model was generated from potential solar beam radiation input at the appropriate latitude, and then it was adjusted for the slope/aspect characteristics of each subunit. These values were further adjusted by empirically derived thermal factors to obtain an index of incident shortwave radiation each day. Peak seasonal snow accumulation was generally estimated from snow courses observed by the USDA Soil Conservation Service.

Rocky Mountain/Intermountain Hydrologic Region (4)

Mean annual water balances for representative watersheds in the Rocky Mountain/Inland hydrologic region (4) are summarized in table III.C.1. The Subalpine Water Balance Model was calibrated and validated on each. The simulation

Table III.C.1.—Mean annual water balances (in inches) for typical subalpine watersheds in the Rocky Mountain/Inland Intermountain Region

Watershed	Seasonal snowpack, water equivalent	Precipitation	Evapotranspiration	Runoff
Colorado:				
Soda Creek, Routt NF	42.6	55.2	16.7	38.5
Fraser River, Arapaho NF	15.0	30.3	16.9	13.4
Wolf Creek, San Juan NF	26.2	48.0	21.0	27.0
Trinchera Creek, Sangre de Cristo Mountains	9.5	19.6	14.5	5.1
Wyoming:				
South Tongue River Bighorn NF	15.5	29.6	15.8	13.8
Montana:				
W. Ford Stillwater River, Custer NF	30.1	49.1	17.0	32.1
Idaho:				
Diamond Creek, Caribou NF	15.2	23.6	14.7	8.9

analysis for Wolf Creek, located in the San Juan National Forest, Colorado is summarized below.

Leaf (1975) has previously summarized hydrologic simulation analyses on Wolf Creek. The watershed (fig. III.C.1) was divided into 11 hydrologic subunits that vary according to slope, elevation, aspect, and forest cover (table III.C.2). The water balance was simulated on each subunit; area-weighted responses were computed and summed to obtain the overall response for the entire basin. Both time and spatial variations were thus taken into account. Further division of forest and open areas resulted in a total of 20 subunits used for the simulation analysis (fig. III.C.2).

Daily temperature extremes in each of the subunits were estimated by extrapolating published temperatures at Wolf Creek Pass 1E, a cooperative station operated by the National Weather Service. Because reliable long-term radiation data were not available in the Wolf Creek area, shortwave radiation input to the model was generated from potential solar beam radiation at 38° N latitude and adjusted for the slope/aspect characteristics of each subunit. These values were further adjusted by empirically derived thermal factors to obtain an index of incident shortwave radiation each day. Peak snowpack accumulation on Wolf Creek was estimated from snowcourse transect data collected by the USDA Soil Conservation Service and by private contractors in the pilot project area. To insure proper snowpack accumulation, the base station daily precipitation was adjusted until the specified water equivalent on each subunit was reached to correct for errors in the spacially extrapolated precipitation data.

Model Calibration

Eleven water years (1958-1968) were simulated during calibration studies on Wolf Creek. Published streamflow data during five subsequent years (1969-1973) were then used to validate the simulated output for the same period. This analysis is shown in table III.C.3 on a monthly residual volume basis to obtain a direct comparison between potential excess water and the observed snowmelt hydrograph. Streamflow data were adjusted to account for diversions from Wolf Creek via the Treasure Pass Ditch (U.S. Dep. Inter., Geol. Surv. 1969-1973).

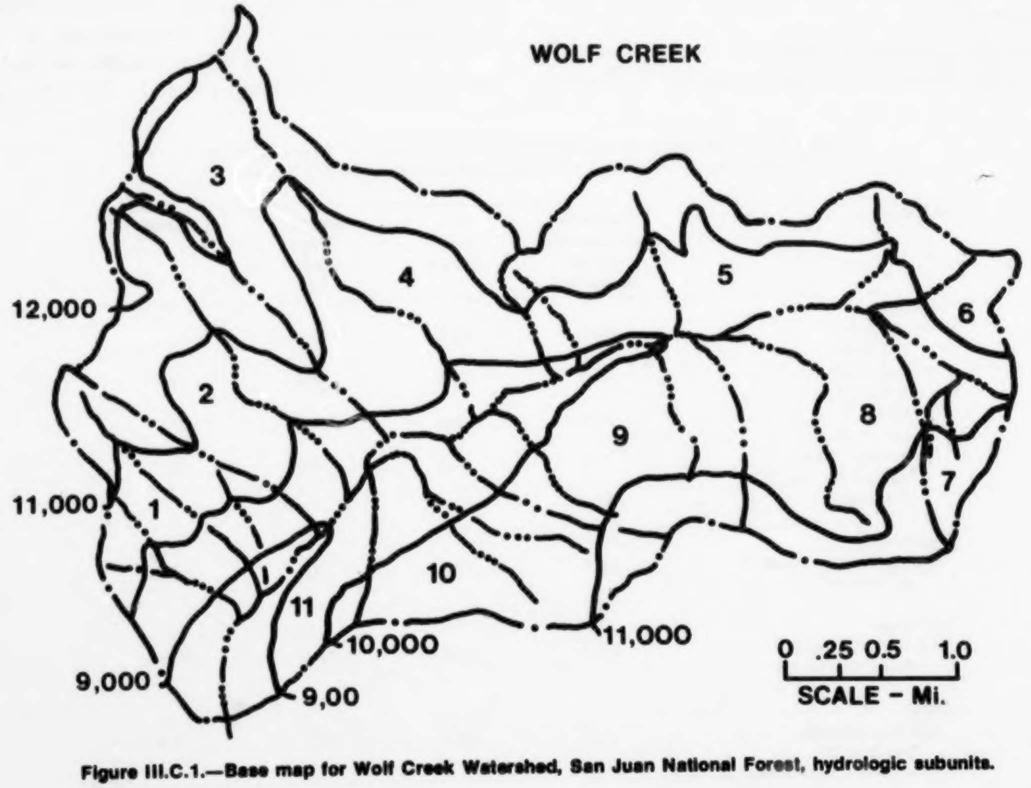

Figure III.C.1.—Base map for Wolf Creek Watershed, San Juan National Forest, hydrologic subunits.

Table III.C.2.—Geographic description of the drainage basin, Wolf Creek watershed, Colorado (see figure III.C.1.).

Hydrologic subunit	**Area** (sq. mi.)	**Percent of total area**	**Sub-unit code**	**Percent of division**	**Percent of basin**	**Average elevation** (ft)	**Average aspect**	**Average slope** (%)	**Remarks**
1	1.4	10.3	1FW-0	64.5	6.6	10,000	SE	40	Forest
			1OW-0	35.5	3.7	10,500	SE	40	Open
2	1.8	12.6	2FW-0	35.4	4.5	10,000	SE	30	F
			2OW-0	64.6	8.1	11,500	SE	40	O
3	1.5	11.0	3FW-121	51.3	5.6	10,750	E	20	F
			3OW-121	48.7	5.4	11,500	SE	40	O
4	1.4	9.8	4FW-160	54.6	5.4	10,750	S	20	F
			4OW-160	45.5	4.4	11,000	SW	45	O
5	2.1	14.8	5FW-192	56.2	8.3	10,750	S	35	F
			5OW-192	43.8	6.5	11,250	S	40	O
6	0.4	2.6	6FW-196	50.0	1.3	11,100	SW	30	F
			6OW-196	50.0	1.3	11,100	SW	20	O
7	0.4	3.1	7FW-9	73.4	2.3	10,900	N	15	F
			7OW-9	26.6	0.8	11,000	N	15	O
8	1.6	11.2	8FW-9	86.0	9.7	10,750	N	10	F
			8OW-9	14.0	1.5	11,000	N	10	O
9	1.5	10.8	9FW-45	100.0	10.8	10,500	NW	20	F
10	1.3	9.5	10FW-45	100.0	9.5	10,000	NW	15	F
11	0.6	4.3	11FW-76	68.6	2.9	9,250	NW	45	F
			11OW-76	31.4	1.4	9,000	W	50	O
Total	14.0	100.0			100.0				

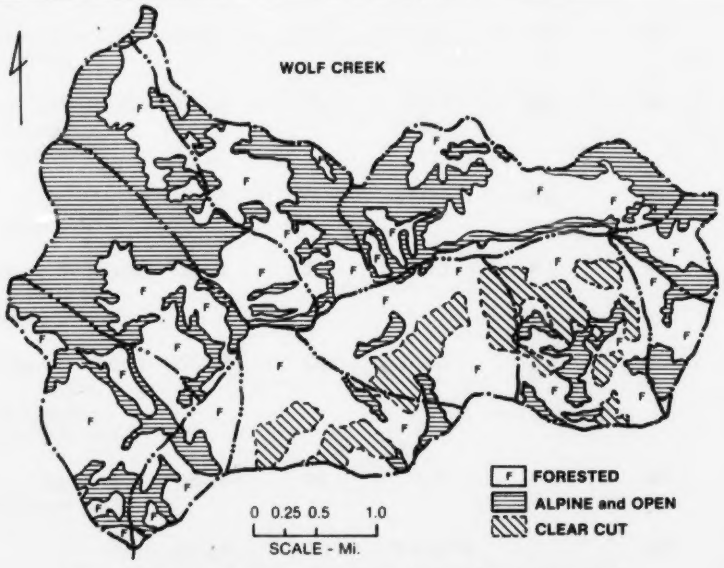

Figure III.C.2.—Extent of forest cover on Wolf Creek Watershed.

Table III.C.3.—Streamflow data (1969-1973) on a monthly residual volume basis, (inches) adjusted to account for diversions from Wolf Creek.

Year	May	June	July	Aug.	Total
1969	0.08	0.25	0.07	0	0.40
1970	0.05	0.32	0.07	0	0.44
1971	0.04	0.33	0.03	0	0.40
1972	0.19	0.17	0.00	0	0.36
1973	0.02	0.56	0.36	0.01	0.95

Continental/Maritime Hydrologic Province (6)

In order to simulate the impacts of vegetative manipulation in the Continental/Maritime hydrologic province (6), an 8.1 square mile watershed at the Corps of Engineers' Upper Columbia Snow Lab (UCSL) was used as a study area (U.S. Army 1956). The watershed is Skyland Creek, a headwaters stream that supplies Bear Creek, a tributary of the Middle fork of the Flathead River in northwest Montana. Skyland Creek is representative of most of the mountain watersheds in Montana west of the Continental Divide, with the possible exception of the Kootenai drainage.

Skyland Creek watershed was divided for analysis into seven subunits, with the objectives of homogeneity with respect to slope, aspect, and elevation, and proximity to a channel to reduce the impact of routing (table III.C.4). Several energy slopes are represented. Skyland Creek is in an elevation zone (5,000 to 7,500 ft.) that can be considered "high" in the northern Rockies. Low elevation zones (2,500 to 5,000 ft.) were also simulated.

Table III.C.4.—UCSL substation description

Sub Unit	Area (relative to total)	Slope	Aspect	Cover— Type[1]	Cover— Density	Elevation	General description
	percent	percent			percent	× 100 ft	
1	4	40	W	S-F	20	65-75	High steep breaklands; High energy
2	10	25	NE	S-F	40	55-69	High moderate slope ridge; Low Energy
3	21	20	NE	LPP	60	49-58	Middle-high gentle slope to stream; Low energy
4	11	25	SW	LPP	40	52-64	High ridge; High energy
5	15	45	N	LPP	60	52-65	Middle-high steep ridge to stream; Very low energy
6	31	30	S	LPP	20	53-75	Middle to high moderate slope ridge to streamside; Very high energy
7	9	30	SW	S-F	20	59-69	High ridge; Very high energy
Composite	100 (8.1 sq. mi.)	30		23% S-F	39	49-75	

[1] Vegetation types: LPP = Lodgepole pine; S-F = Spruce-fir

The technique will be outlined later in this report. "Middle" elevation zones in this region are probably not significantly different with respect to commercial timber harvests; therefore, only two zones were simulated.

Data for the calibration and validation phases were derived from *Snow Hydrology* (U.S. Army 1956) and the associated logs. Water years (WY) 1947 through 1949 were used for calibration. Calibration consisted of manipulation of several parameters to enable the model to reproduce the observed water balance and distribution of runoff in the three years. Validation consisted of running the calibrated model on three subsequent years (WY 50-52) to compare the resulting output with the observed hydrograph (table III.C.5).

Potential solar radiation was derived from Frank and Lee (1966). Cover densities and vegetation types were estimated from aerial photos and the text (U.S. Army 1956). Potential evapotranspiration by month was derived by Thornwaite's method and modified by observed data. Soil moisture holding capacities were developed from comments in the text, and modified by energy-elevation-vegetation observations. Transmissivities (T) used are generally higher by .10 than those suggested by the relationship $T = .19\ C_d^{-.4}$ developed by Leaf and Brink (1973 b) in the central Rockies. Transmissivity in the model controls the incoming direct solar radiation to the snowpack surface only. The model is very sensitive to T with respect to the ripening of the snowpack. The higher T's were necessary in the northern Rockies to make the pack isothermal at an early date. Increases in the corresponding cover densities (C_d) increases the sublimation/evaporation losses beyond reasonable limits. Note that C_d used in the model is highly subjective.

Reflectivity and melt thresholds were initially set at suggested values valid in the central Rockies and then were adjusted to help calibrate the model for Skyland Creek.

Climatic data consisting of maximum and minimum daily temperatures and daily precipitation amounts for the base station at UCSL were derived from laboratory logs for WY 47-52 and from *Climatological Data for Montana* (Natl. Weather Serv. 1953-1963) for WY 53-63. Some of the data for the last 10 years were taken from stations at Summit, Montana, in which case the temperatures were modified by monthly regression equations to the base UCSL station, and precipitation was modified by the long-term annual precipitation ratio between the two stations.

Temperatures from the base station to the substations were modified by regression equations derived from several onsite meteorological stations.

Snowpack data were derived from *Snow Hydrology* for WY 47-49 and from *Water Supply Outlook* in Montana (USDA Soil Conserv. Serv. 1950-1963). Peak dates correspond to reported peak dates. Peak amounts, however, were adjusted to fit the water balance on that date. They do, in fact, approach the observed snow data in most cases. The distribution of snow on each substation was by regression of onsite and nearby snow sites with elevation.

For the years when no observed discharge information was available (WY 53-63), the peak water

Table III.C.5.—UCSL calibration and validation

Water year	Annual precipitation— Obs.	Annual precipitation— Pred.	Annual runoff— Obs.	Annual runoff— Pred.	Runoff efficiency— Obs.	Runoff efficiency— Pred.
	----------------	inches	----------------		--- percent ---	
47	46	46	30	29	65	63
48	45	45	34	29	76	64
49	37	37	22	22	59	60
Calibration						
47-49	43	43	29	27	67	62
50	53	52	24	36	45	69
51	56	56	42	36	76	63
52	35	35	27	23	78	65
Validation						
50-52	48	48	31	32	66	66
All years						
47-52	46	46	30	30	67	64

equivalent was adjusted to force the total precipitation in the model to approximate the observed precipitation.

The model simulated annual hydrographs with accuracy during the six calibration-validation years of WY 47-52 (table III.C.5). Balances and runoff efficiencies were excellent, while timing and general distribution tended to be slightly higher than observed. The average year technique for analyzing response and changes due to treatments tends to smooth annual deviations. However, the deviations themselves will not affect the objectives of this handbook. The model underestimated early and late season runoff, which is probably due to the lack of subsurface routing. This runoff is not very significant with respect to the snowmelt portion of the hydrograph.

The analysis for high elevations was by direct evaluation of the subunits. For low elevations the Skyland Creek watershed was assumed to be 2,000 feet lower.

All temperature intercepts were increased by 4°F. Although all vegetation might be assumed to be ponderosa pine and lodgepole pine, forest cover densities were not changed. The major adjustment for elevation was the reduction of all peak water equivalents to 1/3 the value used in the high elevation simulation. This adjustment is based on a recommendation by Phil Farnes, Montana State Snow Survey Supervisor.[1]

UCSL Simulation Validity

The annual simulated precipitation, runoff, and resulting runoff efficiencies are given in table III.C.5. Water balance predictions are excellent with the exception of WY 1948. Annual deviations are not evident when the six years are averaged.

The model consistently underestimates early and late season base flow which is observed in several of the individual years and is evident still in average year simulation. The volume of water in those periods is very small with respect to the snowmelt portion of the hydrograph. Peaks are simulated slightly higher than those observed and delayed to 6 to 12 days in several years. These deviations are less but still evident in the average year simulation.

Overall confidence in the UCSL simulations is good. Evapotranspiration and soil moisture closely match those observed onsite. Extended data (WY 53-63) is primarily from Summit, Montana. The UCSL station is very similar to Summit. Little error is expected from using Summit data.

Less confidence can be placed on the low elevation modification. Although the changes are based on process and observations, the elevation change is much more complex than the modifications suggest.

Central Sierra Hydrologic Province (7)

In order to simulate the impacts of vegetative manipulation in the Central Sierra region, a 3.96 square mile watershed at the Corps of Engineers' Central Sierra Snow Lab (CSSL) was used as a study area (U.S. Army 1956). The watersheds in north central California.

The Castle Creek watershed was divided for analysis into seven hydrologic units, with the objectives of homogeneity with respect to slope, aspect, elevation, and proximity to a channel to reduce the impact of routing (table III.C.6). Several energy slopes are represented. Castle Creek is in an elevation zone (6,900-9,100 ft) that can be considered "high" in the Sierras. Low elevation zones (3,000-5,000 ft) and middle elevations (5,000-7,000 ft) were simulated with the same watershed. The technique will be outlined later in this section.

Data for the calibration and validation phases were derived from *Snow Hydrology* (U.S. Army 1956) and the associated logs. Data supplied by Dr. Jim Smith, (USDA For. Serv., Berkeley, Calif.), were also used in the analyses. Water years 1947 through 1949, used for calibration, are discussed here. Calibration consisted of manipulation of several parameters to enable the model to reproduce the observed water balance and distribution of runoff in the three years. Validation consisted of running the calibrated model on two subsequent years (WY 50-51) to compare the resulting output with the observed hydrograph (table III.C.7).

Potential solar radiation was derived from Frank and Lee (1966). Cover densities and vegetation types were estimated from aerial photos and text (U.S. Army 1956). Potential evapotranspiration by month was derived by Thornwaite's method and modified by observed data. Soil moisture holding capacities were developed from comments in the text, and modified by energy-elevation-vegetation

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[1] *SCS, personnal communication, 1977.*

Table III.C.6.—CSSL substation description

Sub Unit	Area (relative to total)	Slope	Aspect	Cover— Type[1]	Density	Elevation	General description
	%	%			%	× 100 ft	
1	11	45	SW	Bare	0	79-91	High steep barren tallus; Very high energy
2	15	15	SW	S-F	15	74-79	Middle elevation gentle valleys and hills; High energy
3	10	25	E	S-F	15	73-82	Middle elevation moderate slope; Low Energy
4	26	15	SE	S-F	25	72-82	Middle elevation gentle slope; Moderate energy
5	7	20	N	Bare	0	73-77	Middle elevation gentle slope tallus; Low energy
6	13	20	NE	S-F	25	69-72	Middle elevation moderate slope Low energy
7	18	0	horiz.	S-F	20	73 (river)	Moderate meadows; Moderate energy
Composite	100	30		25% bare 75% S-F	17	68-91	

[1] Vegetation type: S-F = Spruce-fir

Table III.C.7.—CSSL calibration and validation

Water year	Annual precipitation— Obs.	Annual precipitation— Pred.	Annual runoff— Obs.	Annual runoff— Pred.	Runoff efficiency— Obs.	Runoff efficiency— Pred.
	inches				percent	
47	48	48	30	33	63	69
48	63	64	44	44	70	70
49	52	51	33	35	63	68
Calibration 47-49	54	54	36	37	65	69
50	69	69	54	49	79	71
51	81	81	70	62	85	77
Validation 50-51	75	75	62	56	82	74
All years 47-51	62	62	46	45	72	71

observations. Some transmissivities used are somewhat higher than those suggested by the relationship $T = 0.19\,C_{dmax}^{-0.6}$ developed by Leaf and Brink (1973b) in the central Rockies. Transmissivity in the model controls the incoming direct solar radiation to the snowpack surface only. The model is very sensitive to T with respect to the ripening of the snowpack. The higher T's were necessary in the Sierras to make the pack isothermal at an early date.

Reflectivity and melt thresholds were initially set at suggested values valid in the central Rockies and subsequently adjusted in calibrating the model to Castle Creek.

Climatic data consisting of maximum and minimum daily temperatures and daily precipitation amounts for the base station at CSSL were derived from laboratory logs for WY 47-51, from data furnished by Dr. Smith, and from *Climatological Data for California* (Natl. Weather Serv. 1951-1962) for WY 51-62. Some of the data for the last 9 years were taken at Soda Springs, California, in which case the temperatures were modified by monthly regression equations to the CSSL station, and precipitation was modified by the long-term annual precipitation ratio between the two stations.

Temperatures from the base station to the substations were modified by regression equations on onsite meteorological stations.

Snowpack data were derived from *Snow Hydrology* for WY 47-51. Peak dates correspond to reported peak dates. Peak amounts, however, were adjusted to fit the water balance on that date. They approached the observed snow data observations in most cases. The distribution of snow on each substation was by regression of onsite and nearby snow sites with elevation.

For the years when no observed discharge information was available, (WY 51-56, WY 60-62) the peak water equivalent was adjusted so that total model precipitation approximated the observed precipitation. Acceptable annual deviation of predicted to observed precipitation was considered at less than one inch.

The model simulated annual hydrographs during the five calibration-validation years of WY 47-51 (table III.C.7). Balances and runoff efficiencies were good, while timing and general distribution tended to be slightly delayed. The average year technique for analyzing response to changes due to treatments tends to smooth annual deviations. However, the deviations themselves did not affect the objectives of this handbook.

The analysis for high elevations was by direct evaluation of the subunits. For low and middle elevations a similar watershed was assumed 4,000 and 2,000 feet lower, respectively, than Castle Creek. The calibrated model was modified to accomodate the lower elevations by changing two basic parameters. Temperature intercepts were increased by 8° F. and 4° F., respectively. The major adjustment for elevation is the reduction of all peak water equivalents to 0.67 and 0.20 of the value used in the high elevation simulation. These adjustments are based on snow wedge curves (U.S. Army 1956, plate 3-3).

CSSL Simulation Validity.

The validation and calibration years WY 1947 through 1951 water balances are in table III.C.7. The hydrographs of the simulations for these five years are compared with the observed hydrographs on both annual and average bases to offer a level of confidence.

On a year-by-year basis the model had a tendency to underestimate early season runoff during years when these events occur. The model simulated these events with accuracy with respect to timing, but underestimated the magnitudes. Annual peak flows were closely simulated in magnitude; however, there was a consistent delay in the model of perhaps one to six days. This delay was considered to be insignificant since handbook procedures were developed on a seasonal basis. The model tended to be more responsive to inputs yielding more abrupt changes in discharge than those observed. This can be attributed to the lack of subsurface routing of the model.

When all five years were averaged, most of the annual deviations were not evident. Water balances and efficiencies were within one inch (2 percent) of the average observed annual runoff. Simulations of the snowmelt portion of the hydrograph including the spring recession were excellent. Early season (October-November) yields still were underestimated. The 19-inch average annual evapotranspiration and the soil moisture predicted were consistent with those reported in the literature (U.S. Army 1956).

Based on these observations, the simulations of response on Castle Creek are good, especially when considered on an average basis. The annual variability probably closely simulated the actual system. Less confidence, however, can be placed on a single year prediction. (Individual year predictions are not the objectives of the model or its intended use). When forest cover densities are changed in the calibrated model to simulate silvicultural activities, the resulting response should follow the real system. Less confidence can be placed on simulations where the elevations have been assumed lower than Castle Creek. These modifications were based on processes and observed physical phenomena and were extrapolated to reflect watershed conditions at some distance to the south, and at lower elevations.

Alternate Simulations (CSSL)

The Castle Creek watershed as simulated had a relatively low cover density (C_{dmax} = 17%) overall. Two subunits were assumed to be void of significant forest cover. The greatest cover on the remaining five subunits was 25 percent. Therefore, in order to simulate the greater changes in cover density on various energy slopes, the model calibrated for the observed inventory was rerun with all subunits assumed to have an old-growth forest cover density of 0.40, and again at C_{dmax} = .55. This value of C_{dmax} represents a stocking of perhaps 150 square feet per acre. The corresponding values for T were adjusted slightly upward from Lear's relationship of $T = f(C_d)$ consistent with the adjustments made in calibration. The model with this modified C_{dmax} was run with all the other parameters consistent with the original simulation to simulate old-growth commercial forest conditions.

Northwest Hydrologic Province (5)

Vegetation manipulation impacts were simulated for the higher elevation zones of the coastal Pacific Northwest region using data from the Willamette Basin Snow Lab (WBSL) (table III.C.8). The specific watershed is Wolf Creek, a 2.07 square mile mountain headwaters stream in the Willamette River system of west central Oregon (U.S. Army 1956).

Wolf Creek is representative of the commercial timberlands of the region at elevations that accumulate snow and produce a significant snowmelt hydrograph. Simulations of the rain forests at lower elevations in this province are discussed later. The region is under a strong maritime influence. Runoff is in response to both rain and snow, with rain occurring throughout most of the year, except in late summer.

The data base from the Corps of Engineers is inconsistent (Table III.C.9). Reported runoff efficiencies ranged from 94 to 106 percent in the three years

Table III.C.8.—WBSL substation description

Sub unit	Area (relative to total)	Slope	Aspect	Cover— Type	Density
	%	%			%
1	18	20	NE	S-F	60
2	37	20	NE	S-F	60
3	38	35	SE	S-F	55
4	7	0	horiz.	S-F	10
Composite	100 (2.07 sq. mi.)	24			55

Table III.C.9.—WBSL calibration and validation

Water year	Annual precipitation— Obs.	Pred.	Annual runoff— Obs.	Pred.	—Runoff efficiency— Obs.	Pred.
	inches				percent	
49	83[1]	106	88	88	106[1]	83
50	111[1]	130	108	109	97[1]	84
51	106[1]	116	100	98	94[1]	84
47-51	100	117	99	98	99	84

[1] Model calibrated on runoff only. Precipitation data appears to be in error during calibration years.

of record. The precipitation amounts appear to be in error—since they are 20-30 inches below the long-term average. Therefore, calibration consisted of comparing the annual hydrographs with the observed hydrographs for WY 49-51. Precipitation was not a calibration parameter in this case, reducing confidence in the water balance. However, predicted evapotranspiration, soil moisture, and annual runoff were close to the observed values.

Temperature coefficients were regressed when possible against the few onsite stations. Due to the nature of the hydrologic regimen, temperature coefficients were then raised 3° to calibrate the model.

The extended data base from WY 52-60 was derived from Leaburg, Oregon — a nearby station that receives considerably less precipitation and is consistently 4-10° F. warmer. The variability at WBSL was assumed to be represented by that at Leaburg. Precipitation records were modified on an annual basis, while maximum and minimum temperatures were regressed individually on a monthly basis.

The Wolf Creek watershed was divided into four subunits (table III.C.8). Simulations were run on 12 years of climatic record.

WBSL Simulation Validity

Confidence in the WBSL simulation analysis is less than at CSSL or UCSL for four reasons:

(1) The poor data base for precipitation during the calibration years made it difficult to completely verify the water balance.

(2) The maritime influence on snow accumulation causes several different accumulation-depletion events each year with almost constant melt. This is difficult to simulate with the Subalpine Water Balance Model in its present configuration.

(3) Although the average year simulation during the calibration period closely approximates the observed hydrograph, the individual year simulations are more variable in timing and peaks than those observed. This response is masked in the average year output.

(4) The lack of data for validation prohibited assessment of the level of confidence on independent data not used in calibration.

In conclusion, the WBSL simulations reflect regional water balances as reported in the literature, but confidence is difficult to establish to a degree due to lack of long-term small watershed data at high elevations.

APPENDIX III.D: CALIBRATION AND VALIDATION SUMMARY FOR SITES MODELED WITH PROSPER

Since PROSPER is primarily an evapotranspiration model without a routing component, and because the results were being reported in terms of flow duration curves, not hydrographs, calibration efforts were concentrated on simulating annual and seasonal evapotranspiration and in reproducing the observed distribution of flows. Therefore, timing was not a critical design criteria in the calibration scheme. The needs of this handbook dictated accuracy in terms of the distribution of weekly flows.

There are calibration techniques the modeler can employ to improve response, but use of these methods depends on one's philosophy. In terms of PROSPER there are essentially no calibration variables, i.e., variables that do not have a physical basis and/or that cannot be measured. If the user wants the model to represent the physical system, then the variable should not vary from one's best estimate of them. This philosophy was followed in the development of this chapter with two exceptions: Parameters were altered within the expected range of their measured value, and in certain situations, the value of a parameter was altered from its true value if such alteration could compensate for a weakness in the model. In this respect, if storm response was dampened excessively because of routing deficiencies in the model, increases in conductivity of the soil or decreases in its depth might be made to compensate. These adjustments were primarily made to the lower three soil horizons since they did not directly affect the evapotranspiration draft and were, in a sense, dead storage.

A rigorous sensitivity analysis has been done by Luxmoore and others (1976) on PROSPER. In calibration, the water balance is adjusted primarily by changing leaf on/leaf off dates, rooting depth, interception storage, and leaf area index. No changes were made in initial estimates of leaf area index. Interception storage was adjusted to correspond with estimates of interception loss using local equations, and leaf on/leaf off dates were varied over a two-week span. Very little was done to calibrate PROSPER. Initial estimates of the parameters were made.

The following is a description of the application of PROSPER to various representatives and experimental watersheds by region.

THE APPALACHIAN HIGHLANDS AND MOUNTAIN REGION (2)

Watersheds from four areas were used to represent the region. The Leading Ridge Watershed Number 2 in central Pennsylvania, The Fernow Forest Watershed Number 4 in northcentral West Virginia, the Walker Branch Watershed near Oak Ridge, Tennessee, and Coweeta Watershed Number 18 near Franklin, North Carolina were used.

Leading Ridge, Pennsylvania

Leading Ridge Watershed Number 2, operated by Pennsylvania State University, is located in the ridge and valley province in central Pennsylvania. The vegetation on the 106-acre (43ha) watershed consists of mixed hardwoods, primarily oak-hickory, with little understory.

Initial parameter estimates and the necessary data base were provided by James Lynch from the watershed files at Pennsylvania State University. The hydrologic characteristics of the dominant soils were not available, and since the soil series at Leading Ridge was the same as data available at the Fernow Experimental Forest for their soils, the model was run using Fernow soil hydrologic parameters. Because evapotranspiration from the initial calibration run was considered high, the summer interception capacity was lowered from 0.3 cm to 0.25 cm to reduce the simulated evapotranspiration and match the interception loss with that estimated using a local equation.

Four years of climatic data were provided, and the first two years were used for calibration. Calibration results were confounded because of significant rain on snow events, i.e., runoff efficiencies greater than one. The remaining two years of data used to test the calibration also had snowmelt events. Since a significant snowpack generally does not accumulate, and since available snowpack information was deemed unreliable, it was concluded that using the snowpack model, rather than PROSPER, would be unsuccessful. Further attempts at calibration were deemed unnecessary.

An October to September water year was chosen and, with close examination of actual precipitation versus observed streamflow, it can be noted that there is a lag in annual response. Years of high precipitation do not correspond with high levels of flow and vice versa. For the data set as a whole, the simulated streamflow comes within 0.8 percent of the total observed flow. Average predicted evapotranspiration during the 4-year period is 22.3 inches — this compares favorably with the potential evapotranspiration estimated at 22 to 24 inches. Because of snowmelt runoff events, individual observed versus predicted hydrographs ranged from good to poor. Since Hydrologic Region 2 has been characterized as an area where response is not dominated by snowpack accumulation and ablation, and given Leading Ridge's proximity to the border between Hydrologic Regions 2 and 3, it was felt that the simulation would more than adequately represent the hydrologic response with respect to the distribution of flows. A summary of the simulation is represented in table III.D.1.

Table III.D.1—Calibration and validation summary for sites modeled by PROSPER

							Observed versus predicted response		
Water Year	#1 Actual precip.	#2 Transpiration	#3 Interception	#4 Total ET	#5 Flow Q	#6 Changes in soil moisture ΔSM	#7 (Q + ΔSM)	#8 Actual measured OBS Q	#9 Percent deviation
					Leading Ridge				
1961	101.3	39.2	16.8	65.2	41.6	−5.4	36.2	44.0	−12.0
1962	93.7	30.1	14.4	53.5	41.8	−1.6	40.2	41.4	− 2.8
1963	81.0	33.1	14.8	57.1	29.0	−5.1	24.9	22.1	−12.7
1964	91.5	29.3	13.3	51.0	43.5	−3.1	40.4	33.0	+22.0
					Fernow				
1964	141.2	34.2	22.7	64.4	76.2	0.5	76.7	56.4	+26.0
1965	109.7	33.3	26.1	67.1	35.3	7.2	42.5	35.3	+17.0
1968	129.8	33.4	27.0	67.2	62.9	−0.3	62.6	51.6	+17.6
1969	138.3	40.4	31.0	78.9	58.8	0.7	59.5	60.8	+ 2.1
					White Hall				
1966	109.0	61.1	12.1	78.9	25.1	5.5	30.6	26.8	14.0
1967	133.0	68.9	13.9	88.6	37.5	6.5	44.0	36.0	22.0
1968	129.0	65.9	13.8	85.3	40.6	2.7	43.3	37.7	15.0
1969	107.0	63.2	12.4	81.0	25.5	0.6	26.1	31.9	18.0
1970	121.0	60.0	12.3	78.0	37.2	6.0	43.2	33.1	14.0
1971	132.0	73.1	15.5	94.7	37.1	0.5	37.6	41.1	8.0
					Oxford				
1966	121.0	57.6	21.0	83.2	38.6	−0.4	38.2	13.4	185.0
1967	132.0	57.5	24.8	86.9	43.9	0.7	44.6	15.2	193.0
1968	159.0	56.4	24.9	85.8	72.3	0.9	73.2	46.8	156.0
					H.J. Andrews				
1973	167.6	52.1	38.2	94.0	82.8	− 9.2	73.6	72.9	+ 1.0
1974	303.0	45.1	28.0	80.0	251.0	−24.0	227.0	213.0	+ 6.6
1975	232.8	47.9	41.4	92.8	162.1	−22.1	140.0	151.2	− 7.4
					Hubbard Brook				
1971	125.1	30.4	13.1	53.2	70.3	1.4	71.7	66.7	+ 7.5
1972	139.2	25.2	13.1	46.7	89.4	2.5	91.9	104.5	−12.1
					Coweeta				
1972	236.3	53.1	26.5	87.3	134.9	14.1	149.0	135.8	− 9.7
1973	229.4	50.2	23.4	81.7	144.5	3.1	147.6	150.3	− 1.8
1974	221.4	50.3	24.0	82.3	141.2	−2.3	138.9	135.9	+ 2.2

Fernow, West Virginia

The Fernow Experimental Watersheds are operated by the U.S. Forest Service, Northeastern Forest Experiment Station. Fernow Watershed Number 4 was used. This 95-acre (38 ha), mixed hardwood forest was chosen to represent the central Appalachians, particularly the Allegheny Mountains, and is located near Parsons, West Virginia.

The data set and initial parameter estimates were provided from the files at the Fernow Experimental Forest by Northeastern Forest Experiment Station. Numerous changes were made in the parameter set before PROSPER was considered calibrated on the watershed. However, most of these changes entailed a sensitivity analysis to become familiar with PROSPER. The final parameter set differed from the initial one only in that the first two soil layers (of five) were decreased slightly in depth to enable PROSPER to execute more efficiently. A slight adjustment was also made in the distribution of roots between the two upper horizons. The dates at which the canopy was 50 percent on and 50 percent off were increased and decreased slightly to decrease ET and increase early summer and fall storm response.

Four years of climatic data were available. Calibration was done on the first two years of data. The water year selected started May 1, and individual hydrograph simulation was considered good, although, as was frequently the case, timing was slightly offset to the right of the observed hydrograph because of routing deficiencies. Annual potential evapotranspiration, estimated by classical methods, ranged from 23 to 25 inches. Average annual simulated evapotranspiration was 27.3 inches. Thus, PROSPER slightly overestimated evapotranspiration. A direct comparison between observed and predicted flows is shown on table III.D.1. Watershed Number 4 has a poor precipitation runoff relationship, and we expected to simulate more streamflow than was observed. Leakage in Fernow Watershed ranges from 1 to 10 or more inches.

Walker Branch, Tennessee

The normal calibration and validation procedure was unnecessary in this case since PROSPER was developed and tested on Walker Branch. A calibrated parameter and data set was provided by Dale Huff at the Oak Ridge National Laboratories. Walker Branch is located in eastern Tennessee, and vegetation consists of mixed hardwoods, primarily oak, hickory, and yellow poplar. A more thorough description of the calibration and sensitivity analyses can be found in the PROSPER Documentation (Goldstein and others 1974).

Coweeta, North Carolina

The Coweeta Experimental Watersheds are operated by the U.S. Forest Service and Coweeta Hydrologic Laboratory. Watershed Number 18 was used in this study. This watershed is predominantly occupied by mixed hardwoods.

An initial parameter set was provided by Lloyd Swift of the Coweeta Hydrologic Laboratory. Calibration of PROSPER at this site proved to be the most difficult calibration effort encountered, due to some unique hydrologic features of the watershed. The hydrologically active soil-regolith varies from 30 to 100 feet. This gives a strong baseflow component with a long resonance time. However, the watershed also exhibits relatively strong storm response during the dormant season. Thus, the watershed is able to route water through the system via several pathways. PROSPER is unable to simulate such a system, especially where it is as strongly defined as at Coweeta. Numerous changes were made in the initial parameter set in order to achieve a parameter set which represented an acceptable compromise between baseflow simulation and storm response. Since the initial parameter set produced outflow response which was considerably more "flashy" than the actual, soil depths were increased and soil conductivity values were decreased in an effort to dampen storm response.

Three years of climatic data were provided. One year was used in model calibration. The water year started May 1. Hydrograph simulation was considered fair; however, timing was offset to the right. Simulated annual water balance was very good. Mean total evapotranspiration was 33 inches. Considering this is a north-facing watershed, it compared favorably with an average pan evaporation of 35 inches.

The 1973 water year was used as the base for the simulation runs. This year had the most representative lower end of the resulting flow duration curve. Since the effects of timber harvesting in this area are most pronounced at low flow periods, the 1973 year was chosen as being the most representative.

The comparison of simulated or observed flow is shown in table III.D.1.

THE GULF AND ATLANTIC COASTAL PLAIN/PIEDMONT REGION

This region was characterized by simulations using data sets from two experimental watersheds: The White Hall Watershed on the Georgia Piedmont near Athens, Georgia, and Oxford Watershed Number 2 on the Gulf Coastal Plain near Oxford, Mississippi.

White Hall, Georgia

White Hall is a small 60-acre experimental watershed located on the Piedmont near Athens, Georgia, and is operated by the University of Georgia. Vegetation consists of mixed pine-hardwoods typical of the revegetated cottonlands common in the region. Initial parameter estimates and the climatic data set were provided by Dr. John D. Hewlett of the University of Georgia.

Only minor adjustments were made in the initial parameter set. Initial estimates of soil depth were cut in half to remove a considerable delay in storm response. Saturated conductivity rates for the soil profile were revised when more specific onsite information became available to Dr. Hewlett.

Six years of data were provided. Calibration was carried out on the first three years. Very little calibration on the data set was needed once the revised soils data were provided.

For convenience, May 1 was used as the start of the water year because the date generally occurred just after the seasonal peak and antecedent conditions were similar from year to year. PROSPER predicted 225 area inches of outflow for the 6-year period; 207 area inches were observed, resulting in an average error of 9 percent. Average estimated evapotranspiration during the period was 33.2 inches.[1] Given this average and the total predicted outflow (assuming some watershed or weir leakage), the results can be considered very good. The individual yearly values are shown in table III.D.1.

The year starting May 1, 1971, was selected as the basis for the simulation runs. This year most closely resembled the average simulated flow duration curve. It was three inches above normal in terms of total annual precipitation.

Oxford, Mississippi

The Oxford Experimental Watersheds are located on the Coastal Plain in northern Mississippi. They are operated by the U.S. Forest Service, Forest Hydrology Laboratory, Southern Forest Experiment Station. Watershed Number 2 was selected for use here. Watershed Number 2 is a small, 4.6-acre pine-hardwood watershed. Initial parameter estimates and data set were provided by Mr. Stan Ursic at the Forest Hydrology Laboratory.

The only deviation from the original parameter given us was a slight adjustment in interception capacities of the vegetation.

Three years of data were reduced to a form required by PROSPER. Normal evaluation of model response cannot be made because a substantial portion of basin outflow (approximately 10 inches per year) is lost[2] to deep seepage or does not appear in the channel at the weir site; therefore, the calibration goal was to simulate the estimated annual evapotranspiration and to simulate the occurrence of the observed storm response in terms of timing, not peaks. Relative to these goals the results of calibration were very good. The estimate of evapotranspiration losses had been derived earlier from soil moisture studies. As expected, the simulations overpredicted the storm response as measured at the weir site. Calibration was carried out on the first two years of the data set and a validation made on the third year.

If the observed outflow is adjusted by the average 10 inches of seepage loss, then the predicted (shown in table III.D.1) versus adjusted observed outflow gives deviations of 1.4 percent, 9.8 percent, and 1.6 percent respectively for three years. Based on an unpublished study by Ursic, annual evapotranspiration averages between 33 and 36 inches per year. Annual evapotranspiration predicted by PROSPER averages 33.6 inches.

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[1] *Personal Communication, John D. Hewlett, University of Georgia.*

[2] *Personal Communication, Stan Ursic, Forest Hydrology Laboratory.*

The 1967 year was chosen as the base for the simulation runs. It had the smallest deviations from normal in total annual precipitation and total annual runoff. It also had the most representative simulated flow duration curve.

PACIFIC COAST HYDROLOGIC PROVINCES — NORTHWEST (5), CONTINENTAL MARITIME (6), AND CENTRAL SIERRA (7) LOW ELEVATION

Data sets for this region were readily available. The H. J. Andrews Experimental Watersheds were the only ones that had data sets conducive to running PROSPER. Watershed Number 2 was selected.

Where available for the PROSPER simulations on Hubbard Brook, the results of simulation, although not used directly, are shown in table III.D.1.

H. J. Andrews, Oregon

The H. J. Andrews Experimental Watersheds are operated by the U.S. Forest Service, Pacific Northwest Experiment Station. They are located in the rain-predominant lower elevations of the Willamette Basin in the Oregon Cascades. The watershed used in this study was Number 2, a 149-acre (60 ha) watershed supporting a heavy Douglas-fir forest.

Information for initial parameter estimates and climatic data was provided by Dr. Dennis Harr, Pacific Northwest Forest and Range Experiment Station. There were no changes from the initial parameter set with the exception of adjusting the interception losses. Three years of climatic data were available.

Both hydrograph simulation and annual water balance were very good. Timing was slightly offset to the right. Average annual evapotranspiration as computed by PROSPER was 47.3 inches, mostly interception.

The 1975 water year was chosen as the basis for the simulation runs. The 1973 water year was very dry in comparison to long-term climatic records. The 1974 water year was unusually wet.

In addition, PROSPER was calibrated to two watersheds in the Lake States, New England region. Marcell Watershed Number 2 near Grand Rapids, Minnesota, and Hubbard Brook Watershed Number 3 were used. The annual balance for both was fairly good, but since a winter snowpack is significant throughout the region, PROSPER simulations distorted the dormant season flows. A decision was made to base the methodology for this region on the Leaf and Brink (1973b) snowmelt model simulations. PROSPER did well in estimating annual evapotranspiration and streamflow, however. Only two years of records were available for the PROSPER simulations on Hubbard Brook. The results of simulation, although not used directly, are shown in table III.D.1.

Chapter IV

SURFACE EROSION

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INTRODUCTION

Over the past 50 years, many attempts have been made to identify soil and site characteristics that can be used as parameters to quantify the amount of accelerated soil erosion on agricultural and forest lands. Most of the models that have been developed are unique to the areas where they were tested and may not be applicable to other locations. Models which estimate the movement of eroded material through a forest environment to a stream channel have not been extensively tested.

The most acceptable model that is used to estimate surface soil erosion on agricultural lands is the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965). Since this equation is not universally applicable to forest environmental conditions, attempts have been made to develop a Modified Soil Loss Equation (MSLE). To adapt the USLE to forest conditions, the cropping management factor (C) and the erosion control practice factor (P) have been replaced by a vegetation-management factor (VM) in the MSLE. Although this approach for quantifying surface soil loss on forest lands appears to be the best method at this time, it has not been extensively tested or validated on forest lands throughout the United States.

The MSLE does not quantify the amount of material that may come from gully erosion or soil mass movement. A suggested method for evaluating gully erosion is presented in appendix IV.A.

The MSLE model is one of several tools to be used when attempting to understand the effects of different management practices on a given piece of land. This erosion model provides only a long term estimate or an index of the amount of soil loss from a given site (Wischmeier 1976). It is only an estimate because: (1) A model, no matter how complex, is a representation of reality and should never be confused with reality (Bekey 1977), and (2) planning creates a model of the future, and hence is an estimate of something that has not yet occurred. However, this model can still be an effective tool for guiding management decisions by testing different approaches against an objective (such as minimizing the amount of sediment that is delivered to a stream) and evaluating the relative magnitudes of the answers.

This chapter also presents a simple graphic model for estimating the quantity of sheet and rill eroded soil material delivered from the source area to a stream channel. Although this model appears feasible for application on all forest lands, it has not been extensively tested. With additional field testing and experience, the range and nature of this model's sediment delivery factors will be modified.

Many of the techniques used to evaluate surface erosion and sediment delivery are based on subjective evaluations of land characteristics. Persons who have the responsibility for evaluating erosion and sediment delivery need a general technical background in soil science and hydrology, as well as field experience in forest management. This chapter presents charts, tables, and formulas that are needed to use the MSLE and sediment delivery index procedures. Examples are provided in both this chapter and chapter VIII to illustrate a systematic approach to quantifying surface soil erosion on forest lands.

DISCUSSION: SURFACE SOIL LOSS

GENERAL CONCEPTS OF SURFACE SOIL LOSS

Surface erosion is the wearing away of the land surface by water, wind, ice, or other geological agents. In this chapter, surface soil loss is dealt with specifically as the mechanical detachment by water of mineral soil particles and organic material from the soil surface. Other forms of erosion such as soil mass movement, piping, and gully are not covered.

The energy for soil particle detachment by water may be provided by rainfall impact and/or shear from flowing water (e.g., runoff). The impact of raindrops on an exposed soil surface breaks down the surface structure and detaches soil particles and individual aggregates from the soil. Unless the soil surface is protected in some way by a low vegetative canopy and a mineral or organic surface mulch, this raindrop and runoff energy can detach tremendous quantities of mineral and organic soil.

Detachment by raindrop impact removes soil uniformly over a broad area of exposed soil. Such soil loss may be almost imperceptible and is usually referred to as sheet or rill erosion. Raindrop splash enables thin, sheet flow to transport detached particles a short distance to areas of more concentrated water flow.

Detachment by overland flow usually occurs with small concentrations of flowing water in rills. Enough flow energy must be available so the hydraulic forces exceed the soil's resistance to detachment. Consequently, little soil detachment by water flow will occur on areas with thin sheet flow, near ridge tops, on very flat slopes, or where surface runoff rates are low.

The separation of surface erosion into rill and sheet components is conceptually useful. Sheet erosion is a product of either raindrop impact or sheet flow and is relatively uniform over the surface. This distinction is important in determining the type of control strategy that might be used (see "Chapter II, Control Opportunities"). If it can be demonstrated that rill erosion is the primary contributor to the surface erosion total, then the control strategy would be directed toward dealing with overland flow as an eroding agent. Such a strategy would vary somewhat both in scope and in general approach from one designed to deal with erosion from raindrop impact or sheet flow.

Further discussion on surface erosion concepts may be found in articles by Bennett (1934), Bennett (1974), Cruse and Larson (1977), Ellison (1947), Foster and Meyer (1975), Guy (1970), Horton (1945), Meyer and others (1975 and 1976), and Smith and Wischmeier (1962).

Detachment By Raindrop Impact

Three principal factors affect the amount of soil detached by raindrop impact. The first factor is the interception of rainfall by the overstory or tree canopy. Dohrenwend (1977) reports that overstory canopies are not likely to protect the forest floor from the erosive impact of raindrops. In some cases raindrop energy is amplified by the canopy when the intercepted water falls as larger drops (Chapman 1948, Trimble and Weitzman 1954). The second factor is interception by the understory. The rainfall energy transmitted through the overstory canopy may be intercepted by an understory canopy — of shrubs, herbs or grass — growing near the surface. The amount of energy reduction, if any, depends upon drop size and fall distance (Dohrenwend 1977). In a natural forest the surface is protected by a third factor, a mat of litter consisting of leaves, needles, and other organic debris accumulated from the overstory and understory canopies. This litter mat absorbs a great deal of the energy reaching the soil surface. If the depth of the litter mat exceeds the penetration depth of the raindrops, it is assumed that no mineral soil will be detached (Simons and others 1975). The net effect of the three layer screen — overstory canopy, understory canopy, and litter — can be a reduction of rainfall impact energy to very near zero at the soil surface.

The litter layer and organic material in contact with the soil will contribute the greatest erosion protection. Reduction of precipitation energy by the overstory canopy is not generally considered to be significant. The overstory plays a greater, though less direct, role by replenishing the litter.

Detachment By Surface Runoff

Any surface runoff that may occur in the natural forested environment generally moves over the soil below the litter layer. The rate of energy expended for this flow is low because water moves through litter at a lower velocity than it would over the surface of bare ground. Consequently, the detachment energy of the water flow and thus the quantity of soil that is detached, both become very low where good litter cover is present.

Where the litter layer is removed or the soil is compacted, the infiltration rate is decreased. This allows a given volume of rainfall to produce a greater proportion of overland flow than would otherwise occur, and more runoff energy is available to be expended on the soil surface.

Environmental Changes Created By Silvicultural Activities Which Affect Surface Soil Loss Potential

In the natural forest environment, soil loss from sheet and rill erosion is usually small. Only when the natural environment is disturbed by logging, road building, fires, or unusual activities, does soil loss increase (Fredriksen 1972) and become a major source of non-point pollution. The environmental changes due to silvicultural activities that are discussed on the following pages often result in increased soil loss due to destruction of the natural protective soil cover, exposure and disturbance of the soil surface, and/or increased runoff.

Reduction of the overstory canopy. — The primary silvicultural activity is felling and logging. Reduction of the overstory canopy decreases rainfall interception and may either cause an increase or decrease in rainfall energy reaching the ground surface, depending on the nature of the storm and characteristics of the canopy. There is some indication that rainfall energy under hardwood canopies may be greater than under conifer canopies (Swank and others 1972, Trimble and Weitzman 1954). If particular canopies intercept and coalesce water droplets, then removal of these canopies could result in lower rainfall energy at the ground surface.

Removal or alteration of understory. — Silvicultural activities often remove or seriously alter the understory vegetation when the objective is to eliminate vegetative competition to promote the regrowth of timber. The result of brush removal is a net reduction in the effectiveness of the understory to intercept precipitation. When this interception value is lost, the rainfall energy moves closer to the ground surface.

Disturbance of the litter layer. — The litter layer, probably the most important factor in the forest environment for absorbing rainfall energy, is subject to damage by forest management activities, such as logging. In cases where logs are dragged repeatedly over the same area, the litter layer may be destroyed and bare mineral soil exposed. Where the litter layer is shallow, the amount of exposed mineral soil may be great. Furthermore, planting and site preparation, designed to favor the establishment of trees, may involve destruction of the protective litter layer. Burning for site preparation may consume the litter layer and expose mineral soil, especially if the fuel is heavy and/or the site is dry. Other activities, such as raking or piling slash, also tend to destroy the litter layer and expose large quantities of mineral soil. The overall effects of these activities are elimination of protective material covering the mineral soil, and soil compaction, which affects the infiltration and erodibility properties of the soil surface.

Creation of bare soil areas. — In addition to the possible changes within felling and logging units, machine-construction of areas such as roads (required to access and remove the timber) and landings can expose extensive areas of mineral soil. These constructed areas usually have few rainfall intercepting surfaces above the soil and are frequently the major source of erosion produced sediment.

Creation of channels. — Using heavy equipment and skidding logs across the soil surface creates ruts, gouges, or channels. When water is collected and concentrated in these channels, flow energy and erosion potential are greater than if an equal amount of water were dispersed over the entire slope area.

Creation of hydrophobic conditions from fire. An extremely hot fire will consume essentially all of the overstory foliage, understory vegetation, and surface litter layer leaving the soil surface exposed to the rainfall energy of future storms. If the soil is coarse textured, it may become hydrophobic following intense burning, i.e., shedding water as runoff rather than allowing infiltration to occur. A hydrophobic soil condition frequently occurs when volatile organic compounds condense on cooler subsurface soil particles during burning and, thereby, leave a thin waxy surface that resists wetting. Since soil non-wettability can increase surface runoff, greater flow energies are available for soil particle detachment and transport.

Creation of other situations. — Soil mineralogy can promote non-wettability in some cases. For example, soils with high amounts of volcanic ash become hydrophobic if they become very dry. Soil microorganisms often create barriers to water infiltration during dry periods. Although these organisms, such as lichens, may protect the soil against erosion, the additional runoff may contribute to soil loss elsewhere on the slope.

PROCEDURAL CONCEPTS: ESTIMATING SURFACE SOIL LOSS

This section discusses the concepts necessary for estimating surface soil loss and for evaluating the individual parameters involved. It is organized according to a conceptual understanding of surface soil loss and corresponds to the flow chart (fig. IV.1).

An outline of the overall procedure for estimating sediment delivery to a stream from surface erosion sources is presented in "The Procedure" section of this chapter. A detailed example for estimating surface soil loss is provided in "Chapter VIII: Procedural Examples." All concepts discussed here are necessary for using the overall procedure.

Two different approaches are recognized by agricultural and forest scientists for estimating surface soil loss. The first of these is an empirical approach — predictive equations developed from analyses of data. The second is the use of process models — models developed through an analysis of cause and effect relationships. Although process models may ultimately be a more flexible tool producing more accurate answers over a wider range of conditions that can be obtained from empirical models, they are still in the development stage. In addition, process models often require more data than are generally available. For these reasons, process models are not recommended as tools for predicting soil loss within the forest environment.

This chapter presents an empirical procedure for estimating soil loss and adapts it to specific silvicultural problems. The Universal Soil Loss Equation (USLE), originally developed by Wischmeier and Smith (1965) for use on midwest agricultural soils, has been modified for use in forest environments. The cropping management (C) factor and the erosion control practice factor (P) used in the USLE have been replaced by a vegetation-management (VM) factor to form the Modified Soil Loss Equation (MSLE). The following discussion of MSLE and its various factors is based on discussions in "Agricultural Handbook 282" (Wischmeier and Smith 1965) and "Upslope Erosion Analysis" (Wischmeier 1972).

The modified soil loss model (MSLE) is:

$$A = R\ K\ L\ S\ VM \qquad \text{(IV.1)}$$

where:

A = the estimated average soil loss per unit area in tons/acre for the time period selected for R (usually 1 year.) It is not intended to reflect climatic extremes of a given year.

R = the rainfall factor, usually expressed in units of the rainfall-erosivity index, EI, and evaluated from the iso-erodent map, figure IV.2 (U.S. Department of Agriculture, Soil Conservation Service 1977).

K = the soil-erodibility factor, is usually expressed in tons/acre/EI units for a specific soil in cultivated continuous fallow tilled up and down the slope.

L = the slope length factor is the ratio of soil loss from the field slope length to that from a 72.6-foot (22.1 m) length on the same soil, gradient cover, and management.

S = the slope gradient factor, is the ratio of soil loss from a given field gradient to that from a 9-percent slope with the same soil, cover, and management.

VM = the vegetation-management factor, is the ratio of soil loss from land managed under specified conditions to that from the fallow condition on which the factor K is evaluated.

Numerical values for each of the factors have been determined from research data. These values may differ somewhat from one field or locality to another; however, approximate numerical values for any site may be estimated using figures and tables present in this chapter or in the example in chapter VIII.

The MSLE procedure can be used as a guide for quantification of potential erosion of different land management strategies *only* if the principle interactions on which the equation is based are thoroughly understood. Failure to understand the equation and its background will lead to misuse and/or invalid interpretation. Each MSLE factor is discussed on the following pages to clarify the assumptions of the model. If the assumptions do not represent the actual processes in the forest environment, then predicted erosion values will not be the same as actual erosion. The MSLE model may be used to compare effects of different land uses on soil loss if the assumptions used for evaluating each factor in the MSLE do not change with changing land uses.

The Rainfall Factor, R

Wischmeier and Smith (in press) reports that the function of the rainfall factor, R, is to quantify the interrelated erosive forces of rainfall and runoff that are a direct and immediate consequence of rainstorms. It reflects all erosive rains occurring throughout the year in addition to annual maxima.

Since the rainfall factor, R, represents an average annual value, the MSLE estimates average annual soil loss. Soil loss estimates should not be made for specific storms or specific time periods without modifying the R factor to include a runoff variable and using other MSLE values appropriate for the specific events. Even then, soil loss estimates for specific events are subject to much greater error than estimates of average annual soil loss.

Energy-Intensity Values, EI

Factor R is based on a rainfall energy-intensity, EI, parameter which is linearly proportional to soil loss when all other factors are held constant (Wischmeier 1972).

The iso-erodent map (fig. IV.2) presents average annual EI values for the contiguous United States. The lines on the map join points with the same erosion-index value (which implies equally erosive average annual rainfall) and are called iso-erodent lines. The value of R in erosion units per year along each iso-erodent is the value of R in the erosion equation.

The average and the maximum storm values at a particular location will vary widely from year to year. An analysis of rainfall records at 181 stations indicated that maximum storm values tend to follow log-normal frequency distributions that are usually well defined by continuous records of from 20 to 25 years (Wischmeier and Smith in press).

EI is an interaction term that reflects the combination of raindrop splash erosion and runoff detachment of soil particles from bare soil. The sum of computed storm EI values for a given time period is a numerical measure of the erosivity of all the rainfall within that period. The rainfall erosion index at a particular location is the longtime-average yearly total of the storm EI values. The storm EI values reflect the interrelations of significant rainstorm characteristics. Summing these values to compute the erosion index adds the effect of the frequency of erosive storms within the year.

Increases in rainfall energy due to driving winds were not included in the rainfall factor (Wischmeier and Smith 1958, 1965). Megahan (1978) suggests that wind can increase rainstorm erosion by as much as one order of magnitude because the force vector of wind increases with the sin of the slope angle. Therefore, on steep slopes wind becomes an important factor.

Determining The Rainfall Factor

R is the number of erosion index units occurring in an average year's rainfall for a site and may either be computed or taken from a prepared map (fig. IV.2).

It is defined as:

$$R = \frac{EI}{100} \qquad \text{(IV.2)}$$

where:

E = the total kinetic energy in foot-tons/acre inch of rain for each storm. For a storm to be included, it must be greater than 0.5 inches (12.7mm) and be separated from other storms by more than 6 hours.

I = the maximum 30-minute intensity in inches/hour for the area, over the same time period used for estimating soil loss.

The EI value for any particular rainstorm can be computed from recording rain gage data with the help of a rainfall energy table published by Wischmeier and Smith (1958).

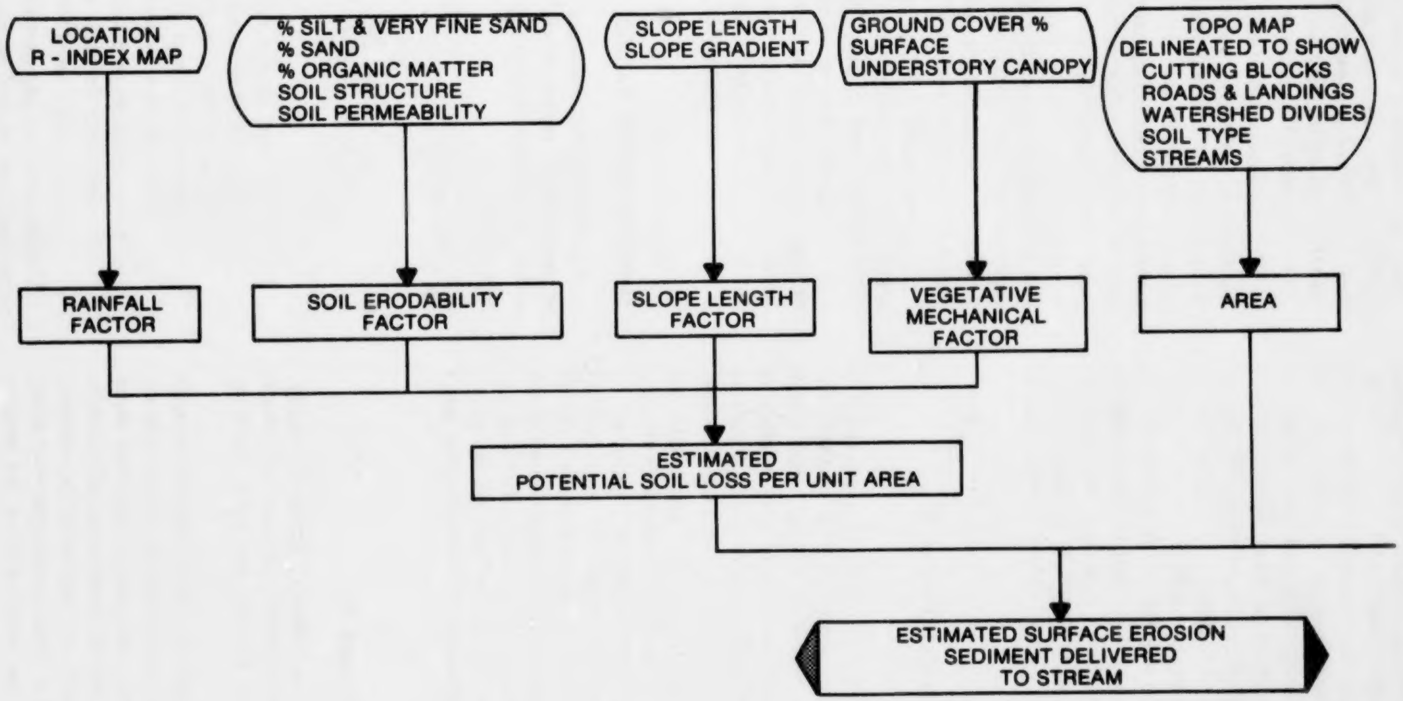


Figure IV.1.—Flowchart of the procedural concepts involved in estimating sediment delivery from surface erosion sources.

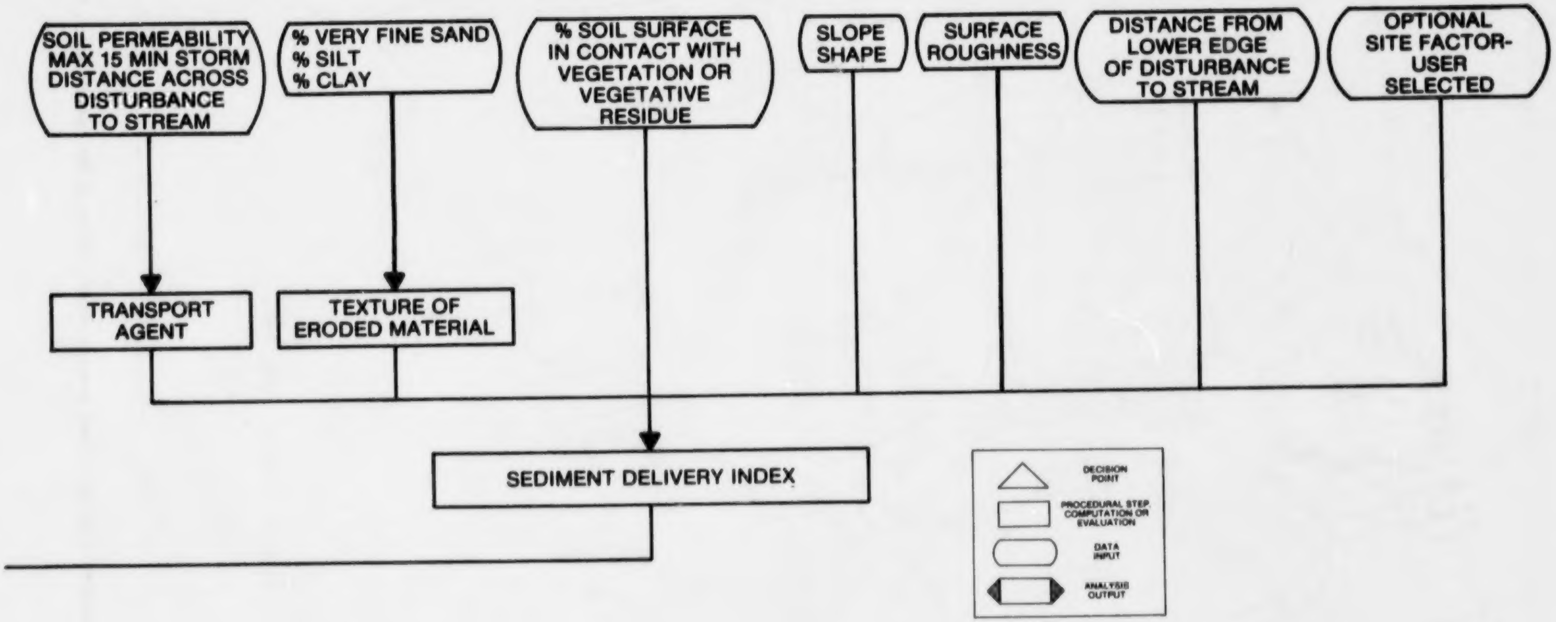
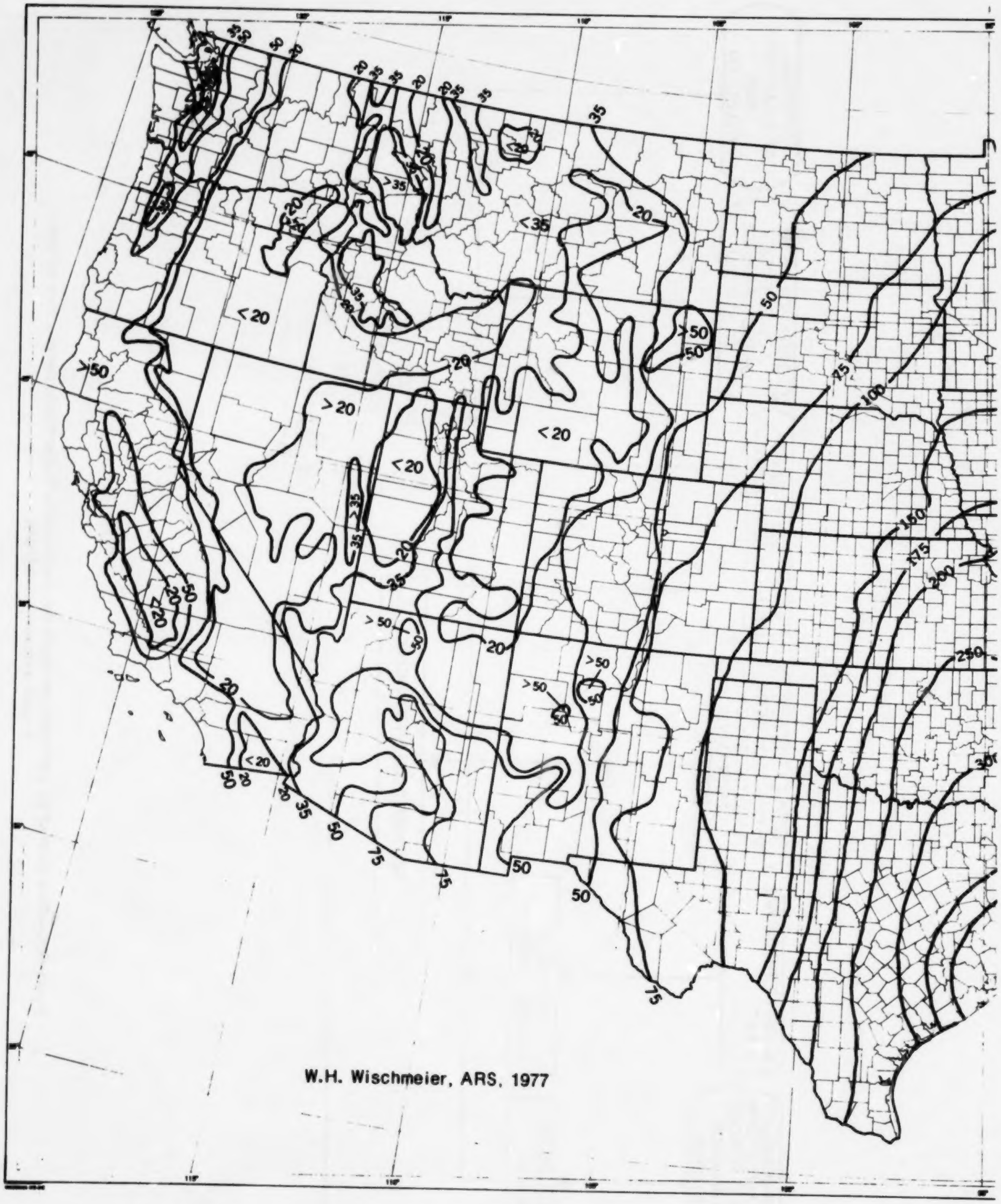

SOIL PERMEABILITY MAX 15 MIN STORM DISTANCE ACROSS DISTURBANCE TO STREAM
% VERY FINE SAND % SILT % CLAY
% SOIL SURFACE IN CONTACT WITH VEGETATION OR VEGETATIVE RESIDUE
SLOPE SHAPE
SURFACE ROUGHNESS
DISTANCE FROM LOWER EDGE OF DISTURBANCE TO STREAM
OPTIONAL SITE FACTOR-USER SELECTED
TRANSPORT AGENT
TEXTURE OF ERODED MATERIAL
SEDIMENT DELIVERY INDEX
DECISION POINT
PROCEDURAL STEP COMPUTATION OR EVALUATION
DATA INPUT
ANALYSIS OUTPUT

Figure IV.1.—Flow chart of the procedural concepts involved in estimating sediment delivery from surface erosion sources — continued.



W.H. Wischmeier, ARS, 1977

Figure IV.2.—Iso-erodent map illustrating average annual values of the rainfall factor, R.

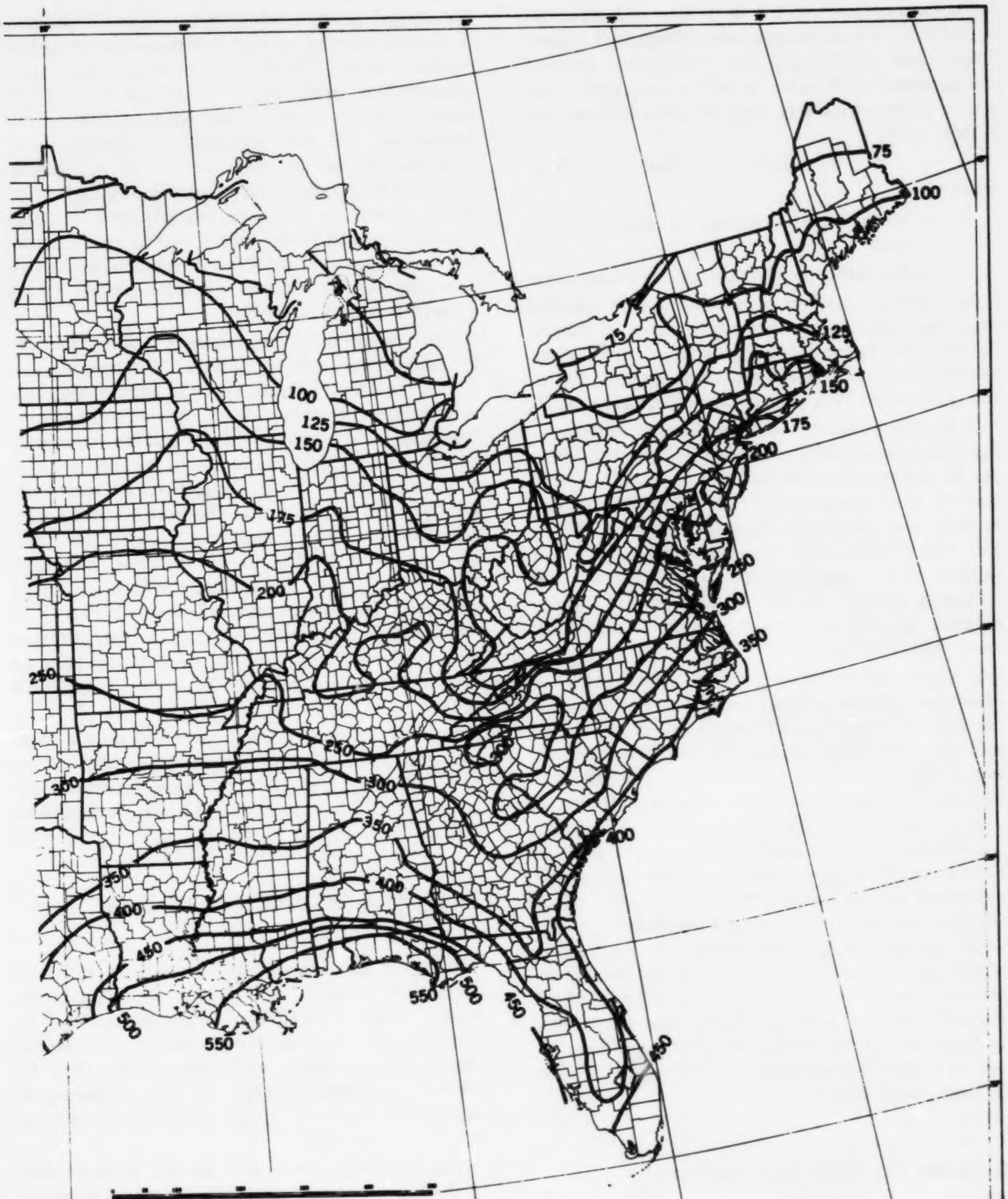


Figure IV.2.—Iso-erodent map illustrating average annual values of the rainfall factor, R — continued.

Research exploring the drop size and terminal velocity of various storm events (Gunn and Kinzer 1949, Laws and Parsons 1943) led to derivation of an equation for E in terms of the intensity of the storm in foot-tons/acre inch as (Wischmeier and Smith 1958):

$$E = 916 + 331 \log_{10} i \qquad \text{(IV.3)}$$

where:

E = storm kinetic energy in foot-tons/acre inch

i = the intensity of the storm in inches/hour

An optional method of determining R requires rain gage data from sites which have 30-minute rainfall records available. Using equation IV.3 and rainfall data, calculate the E value for each storm. Using equation IV.2 and rainfall data, calculate R.

The more commonly used method for determining R is to take locational values of the rainfall factor, R, directly from the iso-erodent map (fig. IV.2) (USDA, Soil Conservation Service 1977). The iso-erodent map shows R values ranging from <20 to 550. The erosion index measures **only** the effect of rainfall when separated from all other factors that influence erosion. Points lying between the indicated iso-erodents may be approximated by linear interpolation.

If all soil and topography factors were exactly the same everywhere, average annual soil losses from plots maintained in continuous fallow, tilled up and down the slope, would differ in direct proportion to the erosion-index values. This potential difference is, however, partially offset by differences in soil, topography, vegetal cover, and surface litter. On fertile soils in the high rainfall areas of the United States, good vegetal cover protects the soil surface throughout most of the year; heavy plant residues, where present, provide excellent ground cover during the dormant season. In the regions where the erosion index is extremely low, good ground cover is often limited to a relatively short period of time. Natural soil erosion may occur both in semiarid regions because of poor ground cover, and in humid regions (with good ground cover) due to high precipitation.

R Values For Thaw And Snowmelt

Wischmeier and Smith (in press) have observed that, in the Pacific Northwest, up to 90 percent of the erosion on the deep loess agricultural soils has been associated with surface thaws and snowmelt runoff. This type of erosion is not accounted for by the rainfall erosion index, but it occurs frequently both in the northwest and in portions of the central western states. With this erosion, the linear precipitation relationship would not account for peak losses in early spring since as the winter progresses, the soil becomes increasingly more erodible. As the soil moisture profile is filled by winter precipitation, the surface soil structure breaks down by repeated freezing and thawing, resulting in puddling, surface sealing and a reduction in infiltration. Additional research on the erosion processes and means of erosion control during snowmelt runoff is needed.

Until research designs a more acceptable method of calculating erosion indices, Wischmeier and Smith (in press) suggest that the early spring erosion by runoff from snowmelt, thaw or light rain on frozen soil may be used in the soil loss computations by adding a subfactor, R_s, to the erosion index to obtain the R factor. Investigations with only limited data indicate that the best estimate of R_s may be obtained by taking 1.5 times the local, December through March, precipitation, measured as inches of water. For example, a location in the northwest that has an erosion index of 20 (fig. IV.2) and averages 12 inches (304.8mm) of precipitation between December 1 and March 31 would have an estimated average annual R factor of [1.5(12) + 20] or 38.

Snowmelt runoff erosion may also be a significant factor in the northcentral and eastern states, particularly on loessal soils. Where experience indicates that this type of runoff exists, it should be included in factor R evaluation.

The Soil Erodibility Factor, K

The term "soil erodibility" is distinctly different from "soil erosion." The rate of soil erosion, designated by A in the soil loss equation, may be influenced more by land slope, rainstorm characteristics, cover, and management than by inherent properties of the soil. This difference in soil erosion, due only to soil properties, is referred to as soil erodibility.

The physical properties of the soil, as they relate to the inherent susceptibility of that soil to erode, are discussed in soil science literature (Barnett and Rogers 1966, Browning and others 1947, Lillard and others 1941, Middleton and others 1932, Olsen and Wischmeier 1963, Peele and others 1945, Wischmeier and Mannering 1967). Wischmeier and

Mannering (1969) developed an empirical expression of soil erodibility as a function of 15 soil properties and their interrelationships. Their equation, however, appeared to be too complex and demanding for general use, and the soil erodibility factor was later redefined in terms of five soil properties.

Soil characteristics that influence soil erodibility by water are: (1) those that affect the infiltration rate, permeability, and total water-holding capacity, and (2) those that resist the dispersion, splashing, abrasion, and transporting forces of the rainfall and runoff (Adams and others 1958). A number of attempts have been made to determine criteria for characterizing soils according to erodibility (Lillard and others 1941, Middleton and others 1932, Peele and others 1945, Smith and Wischmeier 1962). Generally, however, soil classifications used for erosion prediction have been largely subjective and have led only to relative rankings.

The relative erosion hazard (erodibility) of different soils is difficult to judge from field observations. Even soils with a relatively low erodibility factor may show signs of serious erosion under certain conditions, such as on long or steep slopes or in localities having numerous high-intensity rainstorms. A soil with a high natural erodibility factor, on the other hand, may show little evidence of actual erosion under gentle rainfall when it occurs on short and gentle slopes or when the best possible management is practiced. The effects of rainfall, length and degree of slope, and vegetative cover management are accounted for in the MSLE equation by the symbols R, L, S, and VM. The soil-erodibility factor, K, is evaluated independently of the effects of the other factors and will vary depending on the intrinsic properties of the soil.

Original values of the soil-erodibility factor, K, in the MSLE were determined experimentally for agricultural lands. A standard plot for determining K experimentally is 72.6 feet (22.1m) long with a uniform lengthwise slope of 9 percent, in continuous fallow, tilled up and down the slope. Continuous fallow, in this case, is land that has been tilled and kept free of vegetation for a period of at least 2 years or until prior crop residues have decomposed. During the period of soil loss measurements, the plot is plowed and placed in conventional corn seedbed condition each spring and is tilled as needed to prevent vegetal growth or serious surface crusting. This provides a reproducible soil surface condition.

When **all** of these conditions are met, each of the factors, L, S, and VM, has a value of 1.0 and K equals A/EI, where A is the soil loss per unit area (tons/yr) and EI is the erosion index.

For a particular soil, K is the rate of erosion per unit of erosion index from standard plots on that soil. Conditions selected as unit values in the USLE represent the predominant slope length and the median gradient on which past erosion measurements in the United States were made. It is not known if a K factor determined in this manner is completely appropriate for use on forest soils. Until research clarifies this point, K will have to be used on the basis of its original derivation.

Direct measurements of K on replicated standard plots reflect the combined effects of all the variables that significantly influence the ease with which a soil is eroded by rainfall and runoff. To evaluate K for soils that do not usually occur on a 9-percent slope, soil loss data from plots that meet all other specified conditions should be adjusted to a 9-percent slope by means of the slope factor in the Universal Soil Loss Equation (Wischmeier 1972).

Determining The Soil Erodibility Factor

Both the equation and nomograph (fig. IV.3) (Wischmeier and others 1971) for determining K values are discussed. The nomograph can be used for all soils; however, the given equation is limited as described below.

Soil erodibility equation. — Solution of the soil erodibility equation is possible with data normally available from standard soil profile descriptions and routine laboratory analysis. The equation should not be used with soils having more than 70 percent silt and very fine sand or with soils having a low clay content because beyond 70 percent, equation IV.4 no longer fits the nomograph curve. The equation for soil erodibility is:

$$K = (2.1 \times 10^{-6})(12-0m)(M^{1.14}) + 0.0325(S-2) + 0.025(P-3) \qquad \text{(IV.4)}$$

where:

K = soil erodibility factor used in the MSLE.

Om = percent organic matter; if organic matter is >4%, use 4%.

M = particle size parameter: [percent silt (100 − % clay)] where very fine sand (0.05-0.1 mm) is included in the silt fraction.

S = code for soil structure:

Soil Structure Class	MSLE Code
very fine granular	1
fine granular	2
medium or coarse granular	3
blocky, plately, or massive	4

P = Code for Soil Conservation Service permeability classes.
These are for the soil profile as a whole (Wischmeier and others 1971), based on estimated water flow in inches/hour through saturated, undisturbed cores under ½-inch head of water (U.S. Department of Agriculture, Soil Conservation Service 1974):

Permeability class	Permeability rates *in/hr*	MSLE Code
very slow	<0.06	6
slow	0.06-0.2	5
slow to moderate	0.2 -0.6	4
moderate	0.6 -2.0	3
moderate to rapid	2.0 -6.0	2
rapid	>6.0 -20.0	1

General permeability classification guides and discussion from the USDA Soil Survey Manual are presented to help determine the appropriate permeability classification. Soil permeability is that quality of the soil that enables it to transmit water or air. It can be measured quantitatively in terms of rate of flow of water through a unit cross section of saturated soil in unit time, under specified temperature and hydraulic conditions. Percolation under gravity with a ½-inch head and drainage through cores can be measured by a standard procedure involving presaturation of samples. Rates of percolation are expressed in inches per hour.

In the absence of precise measurements, soils may be placed into relative permeability classes through studies of structure, texture, porosity, cracking, and other characteristics of the horizons in the soil profile in relation to local use experience. The observer must learn to evaluate the changes in cracking and in aggregate stability with moistening. If predictions are to be made of the responsiveness of soils to drainage or irrigation, it may be necessary to determine the permeability of each horizon and the relationship of the soil horizons to one another and to the soil profile as a whole. Commonly, however, the percolation rate of a soil is set by that of the least permeable horizon in the solum or in the immediate substratum.

The infiltration rate, or entrance of water into surface horizons, or even into the whole solum, may be rapid; yet permeability may be slow because of a slowly permeable layer directly beneath the solum that influences water movement within the solum itself. The rate of infiltration and the permeability of the plow layer may fluctuate widely from time to time because of differences in soil management practices, kinds of crops, and similar factors (U.S. Department of Agriculture, Soil Survey Staff 1951).

Some guides for using the permeabililty codes are: (1) fragipan soils fall into category 6; (2) soils with surface permeability underlain by massive clays or silty clays should be coded 5; (3) silty clay or silty clay loam soils having a weak angular or subangular blocky structure and moderate surface permeability should be coded 4; (4) if the subsoil structure remains moderate or strong, or texture is coarser than silty clay loam, the code should be 3; and (5) if the soil remains open, does not form surface seals, and the profile does not restrict intake, the code should be 1 or 2.

Soil erodibility nomograph for factor K. — Equation IV.4 is based on the nomograph with one exception — the relationship for K changes when the silt-very fine sand fraction exceeds 70 percent. This change is not included in the equation, but is incorporated into the nomograph (fig. IV.3). Instructions for use of the nomograph are included in the figure.

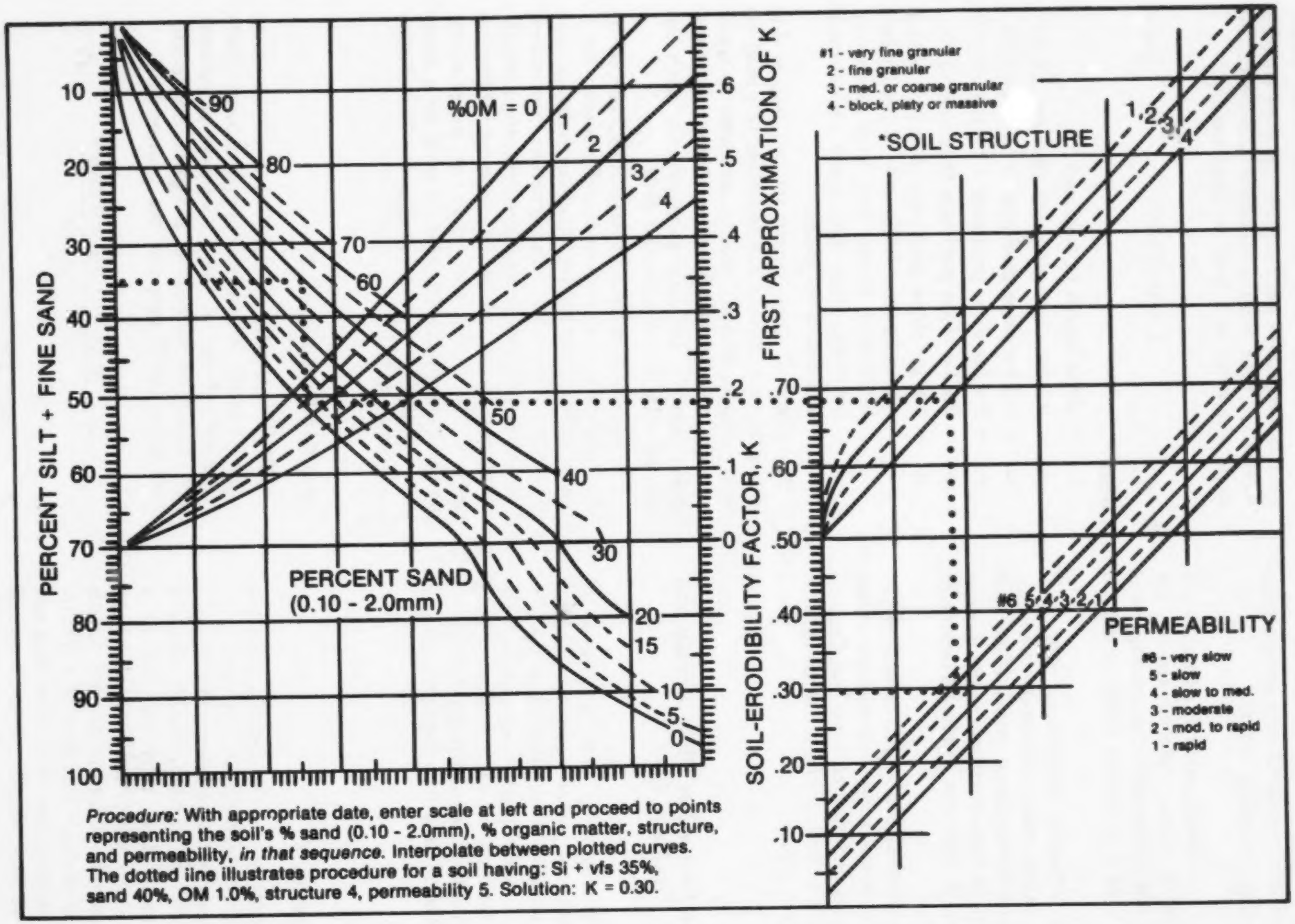
In certain situations, improved K values may be obtained by using the following suggestions:

1. For claypans and fragipans, it may be desirable to use separate erodibility factors for dry and wet seasons by using different permeability ratings in the nomograph. Permeabilities should be reduced in wet seasons, but not for thunderstorms during the dry season (Wischmeier and others 1971). Weighted annual mean erodibility factors for wet and dry seasons can be computed as follows:

$$K = \frac{(K_w M_w + K_d M_d)}{M_w + M_d} \qquad \text{(IV.5)}$$

where:

K = weighted mean erodibility,
K_w = soil erodibility during wet season,



Procedure: With appropriate date, enter scale at left and proceed to points representing the soil's % sand (0.10 - 2.0mm), % organic matter, structure, and permeability, *in that sequence.* Interpolate between plotted curves. The dotted line illustrates procedure for a soil having: Si + vfs 35%, sand 40%, OM 1.0%, structure 4, permeability 5. Solution: K = 0.30.

Figure IV.3.—Nomograph for determining the soil erodibility factor, K.

M_w = number of wet months with erosive rainfall and/or snowmelt runoff,

K_d = soil erodibility during dry season,

M_d = number of dry months with erosive rainfall and/or snowmelt runoff,

2. Large surface material, such as gravel, is not included in K value determinations, but rather is a part of the vegetation-management factor (VM) as it relates to mulch or ground cover.
3. High clay subsoils containing iron and aluminum oxides react differently than surface soils containing those oxides (Roth and others 1974). In this situation the nomograph solution for K may not apply (Wischmeier 1976).

The Soil Conservation Service has determined K factor values for some soils. Information about these tables should be obtained from Soil Conservation Service soil scientists who are familiar with the soils in a given area.

The Topograhic Factor For Slope Length and Gradient, LS

The rate of soil erosion by water is affected by both slope length and slope gradient (percent slope). The two effects are represented in the erosion equation by L and S, respectively. In field application of the equation, however, it is convenient to consider the two as a single topographic factor, LS, because of the interactions between the two parameters.

Slope Length Factor, λ

Slope length is defined as the distance from the point of origin of overland flow to: (1) the point where the slope decreases to the extent that deposition begins; (2) the point where runoff enters a well-defined channel that may be part of a drainage network or a constructed channel such as a terrace or diversion (Wischmeier and Smith 1965); or (3) the downslope boundary of a disturbance. A change in land use on a slope does not change the effective slope length unless the runoff from the upper slope is diverted off of the area in some manner.

Numerous plot studies (Wischmeier 1966) have shown that soil loss in tons/unit area is proportional to some power of slope length. Since the factor L is the ratio of soil loss from the slope length of interest to that from a standard 72.6-foot(22.1m) slope, the value of L may be expressed as:

$$L = (\lambda / 72.6)^m \qquad \text{(IV.6)}$$

where:

λ = slope length in feet, and

m = 0.2 for slope gradients that are ≤1.0%

m = 0.3 for slope gradients >1.0 but≤3.0%

m = 0.4 for slope gradients >3.0 but ≤5.0%

m = 0.5 for slope gradients that are >5.0%

m = 0.6 for slope gradients over 12% with a natural permeability code of 5 or 6 where infiltration is very low, such as on construction sites and roads (Wischmeier and Smith in press).

The effect of slope length on soil loss is due primarily to a greater accumulation of runoff on longer slopes. Runoff velocity increases as water volumes increase, and both detachment and transport capacity increase geometrically with increased velocity (Wischmeier 1972).

The exponent m is significantly influenced by the interaction of slope length and gradient, but it may also be influenced by soil characteristics, type of vegetation, and management practices. Generally, increases in slope gradient, slope length, or increases in runoff (due to reduced infiltration caused by either soil type or vegetation-management practices) create a need for a larger slope length exponent (m) in equation IV.6 (Foster and others 1977).

Slope Gradient Factor, S

A. W. Zingg (1940) concluded that soil loss varies as the 1.4 power of percent slope. Musgrave (1947) recommended use of the 1.35 power of percent slope. Based on analyses of the data, Smith and Wischmeier (1957) proposed the relationship:

$$S = \frac{(0.43 + 0.30s + 0.043s^2)}{6.613} \qquad \text{(IV.7)}$$

where:

s = slope gradient expressed as percent slope, and

S = slope gradient factor.

The data adequately support this slope relationship up to a 20 percent slope. Since the equation is parabolic, slope relationships cannot be extrapolated indefinitely beyond gradients of 20 percent and still obtain accurate estimates of soil loss from the MSLE. However, the MSLE may be used on slopes over 20 percent to compare the soil loss effects of several different management activities.

Determining The Topographic Factor

The LS factor is the expected ratio of soil loss/unit area (tons/yr) on a slope as compared to a corresponding soil loss from the standard plot (9-percent slope, 72.6 feet (22.1 m) long). For specific combinations of slope length and slope gradient, this ratio may be taken directly from a length-slope nomograph (fig. IV.4). For example, a 10-percent slope that is 360 feet (109.7 m) long would have an LS ratio of 2.6.

Values of LS for slope gradients and lengths not shown on the nomograph may be computed using the following equation. A correction factor has been added to equation IV.7 to avoid using sines of angles.

$$LS = \left(\frac{\lambda}{72.6}\right)^m \left(\frac{0.43 + 0.30s + 0.043s^2}{6.613}\right) \left(\frac{10{,}000}{10{,}000+s^2}\right) \qquad (IV.8)$$

s = slope gradient in percent, and

m = an exponent based on slope gradient from equation IV.6.

The use of equation IV.8 or figure IV.4 assumes that the slopes are uniform from top to bottom.

Irregular Slopes

Slopes are usually convex or concave. Use of an average gradient for the entire slope length substantially underestimates soil loss from the convex slopes and overestimates the loss from concave slopes (Foster and Wischmeier 1973). If equation IV.8 or the nomograph (fig. IV. 4) is used on convex slopes, the gradient of the steeper segment should be used as the overall slope gradient for estimating the LS factor. On a concave slope, where deposition may occur on the lower end of the slope, the appropriate length and gradient to use is the point where the slope flattens enough for deposition to occur.

In cases where the slope characteristics change from top to bottom, averaging the slope characteristics and applying one LS factor will not accurately estimate soil loss. The calculations for irregular slopes (Foster and Wischmeier 1973) are recommended on areas where several slopes are combined. This equation accounts for situations where runoff comes from one slope segment and flows to the next. However, if substantial sediment deposition will occur due to a change in vegetative cover or diversion of water, this procedure cannot be used because it does not account for sediment deposition.

Foster and Wischmeier's (1973) equation is presented here, and an example of its use may be found in chapter VIII.

$$LS = \frac{1}{\lambda e} \cdot \sum_{j-1}^{n} \left[\left(\frac{S_j \lambda_j^{m+1}}{(72.6)^m} - \frac{S_j \lambda_{j-1}^{m+1}}{(72.6)^m} \right) \left(\frac{10{,}000}{10{,}000 + s_j^2} \right) \right] \qquad (IV.9)$$

in which:

λe = overall slope length in feet,

j = slope segment index,

λ_j = the length in feet from the top to the lower end of any segment j,

$\lambda_{j\text{-}1}$ = total slope length above segment j,

s = slope in percent,

m = an exponent based on slope gradient from equation IV.6, and

S_j = slope factor $\frac{0.43 + 0.30s + 0.043s^2}{6.613}$ for s^2 segment j (Eq. IV.7)

Foster and Wischmeier (1973) developed an alternative procedure for performing several steps in the solution of equation IV.9 for irregular slopes. The set of graphs (figs. IV.5 and IV.6) eliminates the need for logarithms, a slide rule, or an electronic calculator to raise the slope length values to needed powers. These figures are a family of curves for specific slopes ranging from 0.5 percent to 140 percent. Each figure uses the appropriate value for m as previously discussed.

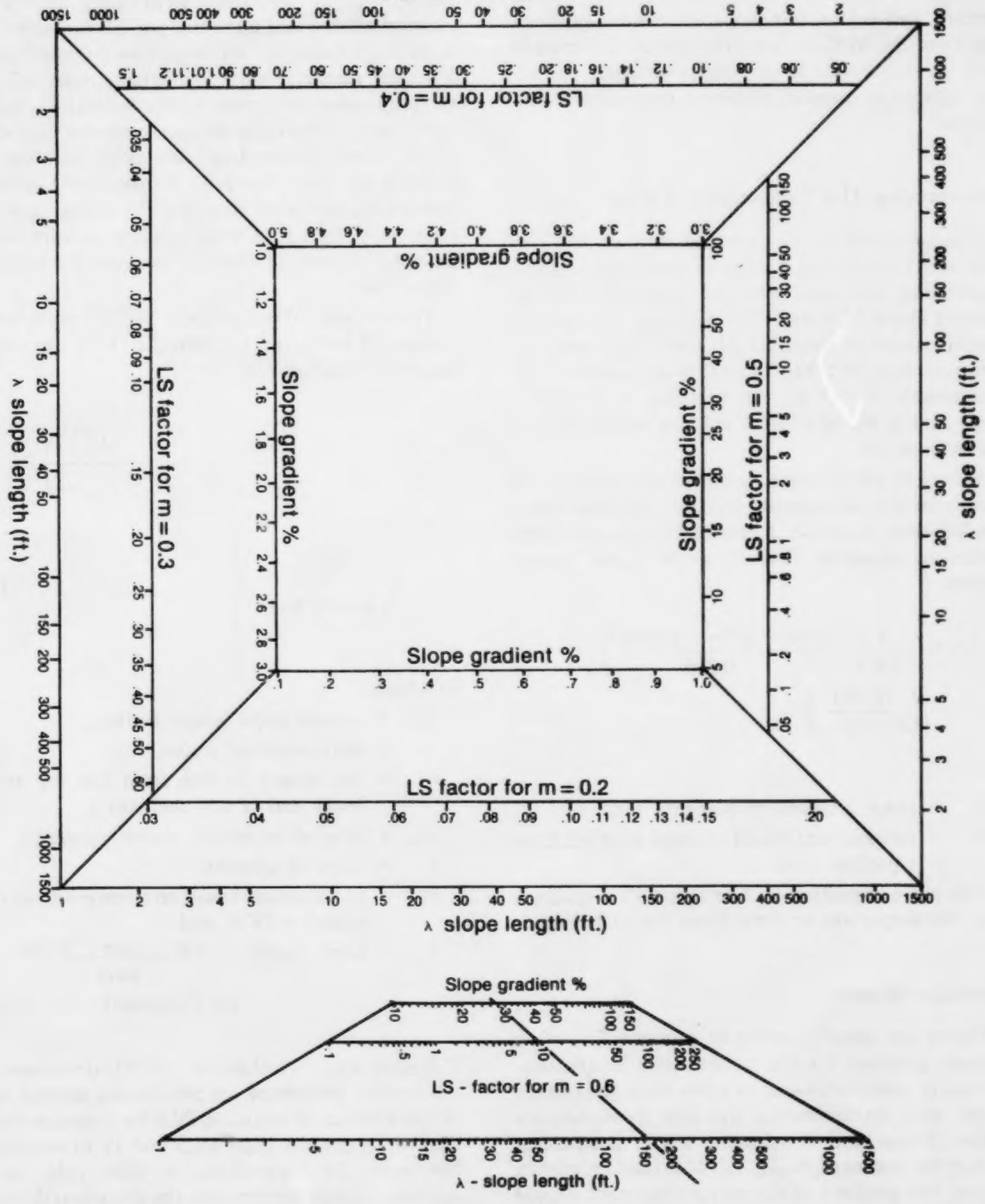


Figure IV.4.—Nomograph for determining the topographic factor, LS, on simple slopes.

The graphs (figs. IV.5 and IV.6) are based on the following equation which is a portion of equation IV.9.

$$\mu = S\left(\frac{\lambda^{m+1}}{72.6^{m}}\right)\left(\frac{10{,}000}{10{,}000 + s^{2}}\right) \qquad \text{(IV.9a)}$$

where:

μ = derived factor for simplifying calculation of LS on irregular slopes,

S = slope steepness factor from equation IV.7,

s = slope gradient in percent,

λ = slope length in feet, and

m = an exponent based on slope gradient from equation IV.6.

The symbol μ is plotted on log-log graph paper against values of slope length with curves for specific slopes within the body of the graphs.

To illustrate the graphic procedure for obtaining the LS factor for irregular slopes, a road with cut-and-fill slopes (fig. IV.7) has been divided into segments representing the cut slope, the roadbed surface, and the fill slope. It has been assumed that sediment will not accumulate on the roadbed. The first segment (cut slope) has a slope length of 4.8 feet (1.46 m) at 66.7 percent gradient, the second segment (roadbed surface) has a slope length of 12 feet (3.66 m) at 0.5 percent gradient, and the third segment (fill slope) has a slope length of 4.8 feet (1.46 m) at 66.7 percent. The values are $\lambda_1 = 4.8$, $\lambda_2 = 16.8$, and $\lambda_3 = 21.6 = \lambda_e$. Data for this procedure are tabulated into table IV.1.

For the first segment, enter figure IV.6 at 4.8 on the horizontal axis, move upward to the curve for 70 percent slope (for greater accuracy, values between can be interpolated) and read $\mu_2 = 29$ on the vertical scale. The upper end of this segment is at zero length so $\mu_2 - \mu_1 = 29$.

For the second segment, use the graph for 0.5 percent slope entering the graph with lengths of 16.8 feet and 4.8 feet. For those, $\mu_2 = 1$, $\mu_1 = 0.25$ and $\mu_2 - \mu_1 = 0.75$. Repeat this procedure for segment 3.

The effective LS for any segment is obtained by dividing ($\mu_2 - \mu_1$) by the length of the segment as illustrated. The overall LS value of 5.8 shown in the last column was obtained by dividing the sum of the ($\mu_2 - \mu_1$) by the total length (124.7/21.6 = 5.8). The detail provided by the last two columns of the tabulation may be helpful in designing effective erosion control practices for each segment.

These values for LS, using this graphic approach, are not exactly the same as those calculated from equation IV.9, as shown in chapter VIII. This is due to errors inherent in using graphs. Although these small errors exist, the numbers determined with the graphs are sufficiently accurate for general use.

Table IV.1.—Example of data tabulation when using graphs for obtaining LS value for irregular slopes

Segment	Slope (%)	λ_j (ft)	λ_{j-1} (ft)	μ_2	μ_1	μ_2-μ_1	Segment Length (ft)	Segment LS
1	66.7	4.8	0.0	29	0.0	29	4.8	6.0
2	0.5	16.8	4.8	1	0.25	0.7	12.0	0.1
3	66.7	21.6	16.8	270	175	95	4.8	19.8
						124.7	21.6	5.8

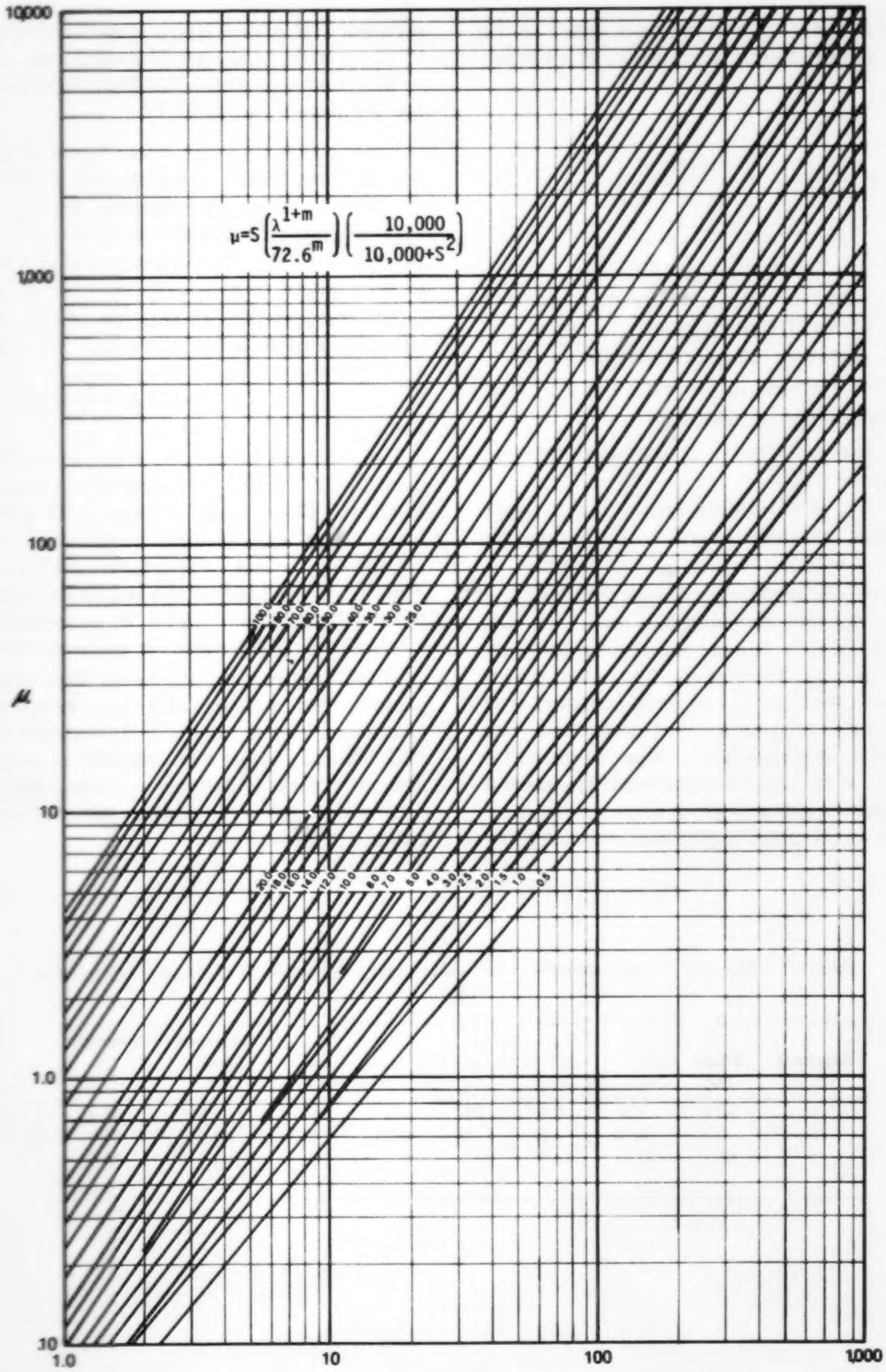


Figure IV.5.—Values of μ for use with irregular slopes (0.5 - 100%) with appropriate values of m (0.2, 0.3, 0.4, and 0.5).

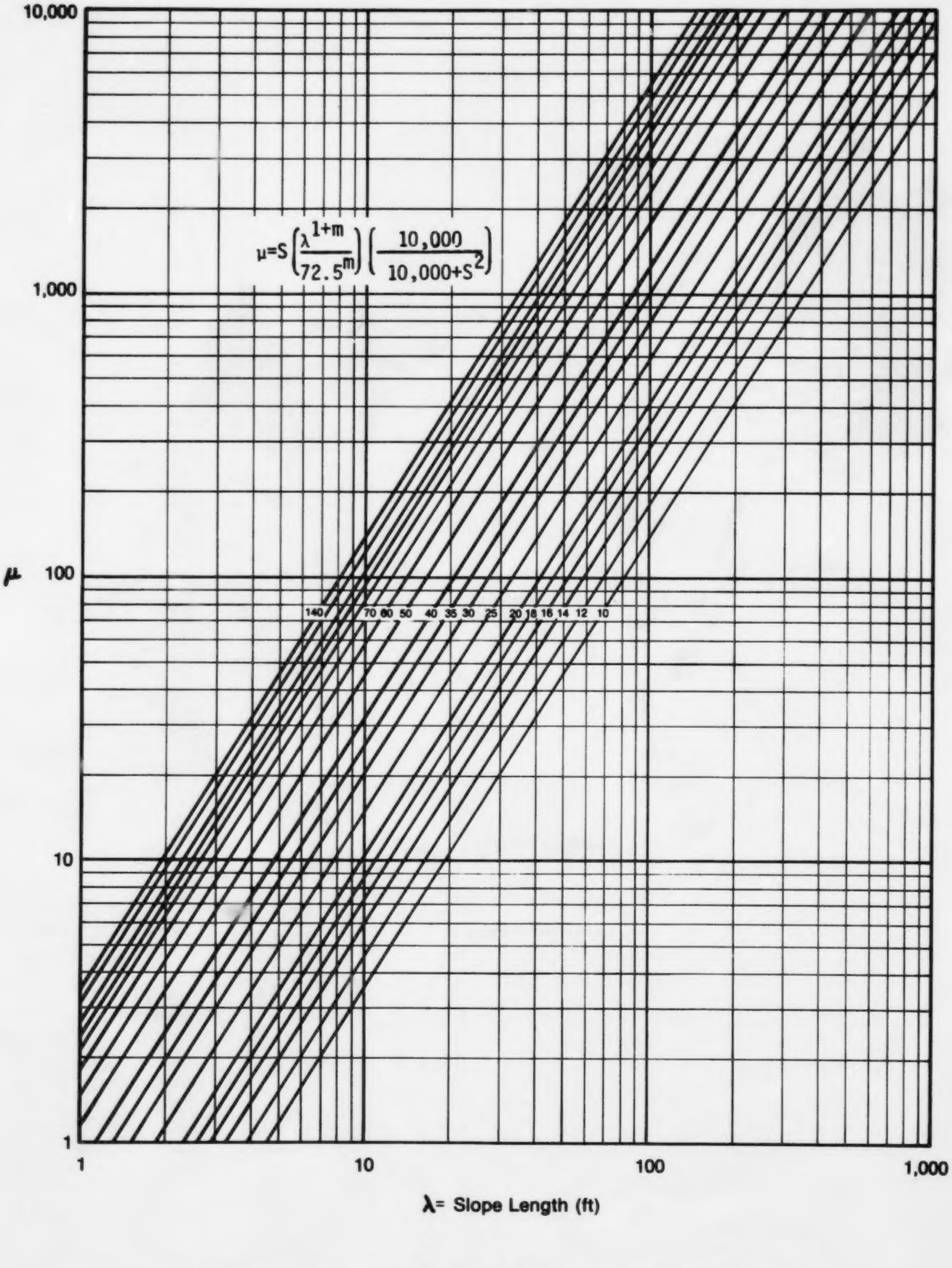


Figure IV.6.—Values of μ for use with irregular slopes (10-140%) where m = 0.6.

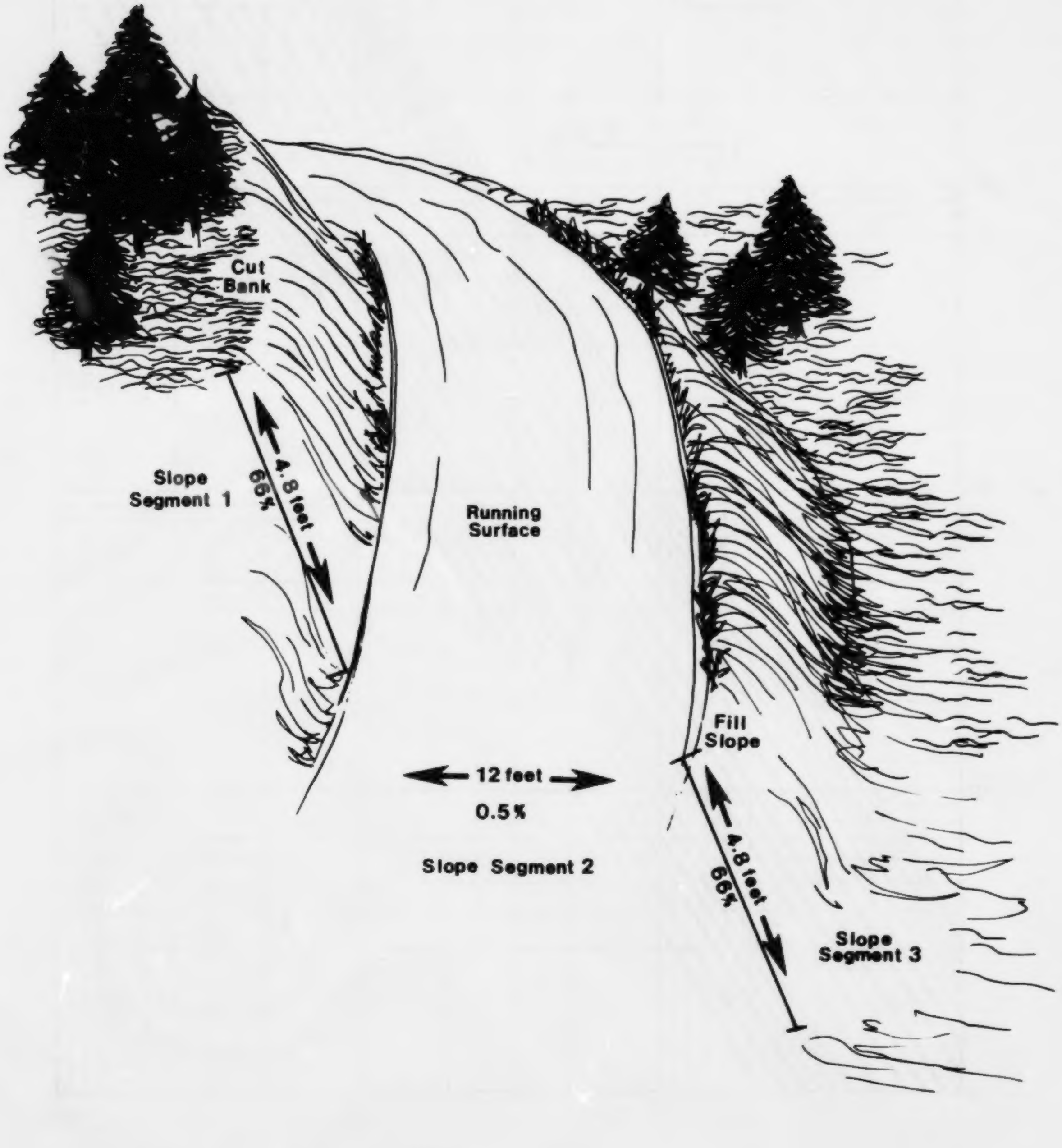


Figure IV.7.—Generalized cross section of outsloped road.

The Vegetation-Management Factor, VM

The effects of vegetative cover and forest silvicultural activities on soil detachment by rainfall and runoff are numerous and varied. Forest residues from silvicultural activities may be removed, left on the surface, incorporated near the surface, plowed under, or burned. When left on the surface, they may be chopped or they can remain as left by the harvesting operation. Seedbeds may be left rough with the capacity for surface storage of rainfall and sediment, or they can be left smooth. Different combinations of these variables and possibly other conditions will have different effects on a soil's susceptibility to erosion. In addition, the effectiveness of residue management will depend on the volume and distribution of remaining residues. This in turn depends on rainfall distribution, on the soil fertility level, and on other management decisions that affect the amount of vegetative productivity on a given site.

The VM factor in the Modified Soil Loss Equation is the ratio of soil loss from land managed under specified conditions to the corresponding loss from tilled, continuously fallow conditions of a standard plot. This factor measures the combined effect of all the interrelated cover and management variables discussed above.

Soil loss that would occur on a particular site if it were in a continuous fallow condition is computed by a product, R K L S, in the MSLE. Actual loss from an area is usually much less than the computed amount; just how much less depends on the particular stage of growth and development of the vegetal cover, and the condition of the soil surface at the time when rain or snowmelt occurs.

The VM factor of the MSLE attempts to combine vegetative cover and soil surface conditions into one numerical factor. Use of the VM factor is facilitated by separating it into three distinct kinds of effects and evaluating each type as a subfactor: Type I — effects of canopy cover, Type II — effects of mulch or close growing vegetation in direct contact with the soil surface, and Type III — residual effects of land use (Wischmeier 1975).

Effects Of Canopy Cover, Type I

Leaves and branches that do not directly contact the soil surface are effective only as canopy cover. Canopies close to the surface have some influence on the impact energy of falling raindrops. Waterdrops falling from a canopy may have appreciable force at the soil surface depending on canopy height and drop size (Dohrenwend 1977).

Figure IV.8, taken from Wischmeier (1975) shows canopy effects of water drops for different amounts of canopy ground cover and canopy heights. If possible, increase in drop size because of canopy interception is ignored, or is assumed to be offset by the fact that some of the intercepted water moves down the stems to the ground. The canopy factors for various percentages of cover at heights of 0.5, 1, 2, and 4 m may be obtained directly from figure IV.8. For a 60 percent canopy cover at a height of 1m, for example, the canopy factor is 0.58. This means that the effective EI with the canopy is only 58 percent of the actual EI of the rainfall, and the expected erosion would also be only 58 percent of that predicted by the EI obtained from the isoerodent map.

Table IV.2—Velocities (m/sec) of falling waterdrops of different sizes (mm) falling from various heights (m) in still air

Median drop diam.	Drop fall height						
	0.5	1.0	2.0	3.0	4.0	6.0	20.0[3]
2.00[1]	2.89	3.83	4.92	5.55	5.91	6.30	6.58
2.25[1]	2.93	3.91	5.07	5.74	6.14	6.63	7.02
2.50[1]	2.96	3.98	5.19	5.89	6.34	6.92	7.41
3.00[1]	3.00	4.09	5.37	6.14	6.68	7.37	8.06
3.50[2]	3.04	4.19	5.55	6.37	6.98	7.79	8.63

[1] Laws J.O. 1941. Measurement of fall-velocity of water drops and rain drops. Transactions of the American Geophysical Union 22:709-721. From Wischmeier 1975.

[2] Extrapolation of values given by Laws (1941).

[3] Values in the last column are considered terminal velocities.

Figure IV.8 is based on a medium drop size of 2.5 mm for both the rain and droplets formed on the canopy. If the 3.35 mm droplets measured by Chapman (1948) on a red pine plantation are assumed to be characteristic for most tree canopies (Trimble and Witzman 1954), figure IV.8 should be modified. When modifying, subfactor values for complete canopy cover can be computed from the data in table IV.2 below for a given diameter using equation IV.10:

$$C_{100} = 0.169V - 0.356 \qquad (IV.10)$$

where:

C_{100} = factor for canopy effect at 100 percent ground cover, and

V = velocity, in meters/second, for a water drop of a given diameter, falling a given distance.

Values for less than complete canopy cover can be found by drawing a line on figure IV.8, from the point calculated for 100 percent cover to the upper left corner where other lines are converging.

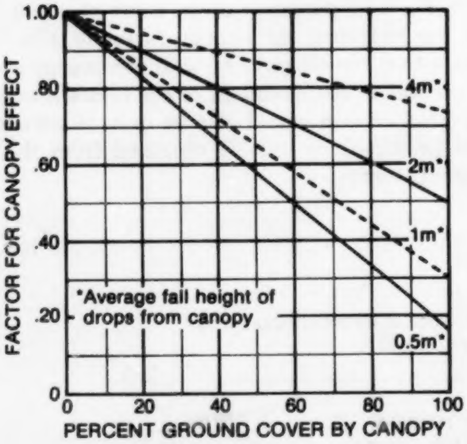


Figure IV.8.—Influence of vegetal canopy on effective EI, assuming bare soil beneath the canopy, and based on the velocities of free-falling waterdrops 2.5 mm in diameter (Wischmeier 1975).

Effects Of Mulch And Close Growing Vegetation, Type II

A mulch on the soil surface is much more effective than an equivalent percentage of canopy cover. There are two reasons for this: (1) raindrops intercepted by the mulch have very little remaining fall height to the ground, and their impact on the soil surface is essentially eliminated; and (2) a mulch that makes good contact with the ground also reduces the velocity of runoff. This, in turn, greatly reduces the runoff's potential to detach soil material.

Effectiveness of type II cover can be expressed on the basis of percent surface cover using the relationship in figure IV.9 (Wischmeier 1975). If the cover includes both canopy and surface mulch, the canopy and mulch factors overlap and the canopy factor can not be fully credited. Impact energy of a raindrop striking the mulch is dissipated at that point regardless of effects of canopy interception on its fall energy. The mulch factor is always taken at full value, and the canopy factor is reduced so that it applies only to the percentage of the soil surface not covered by mulch.

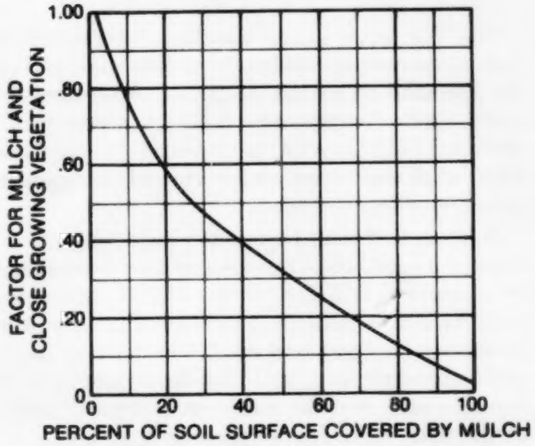


Figure IV.9—Effect of plant residues or close-growing stems at the soil surface on the VM factor (does not include subsurface root effects) (Wischmeier 1975).

To illustrate this, assume a 30 percent mulch cover combined with a 60 percent canopy at a height of 1 m. From figure IV.9, the factor for mulch cover effect is 0.47. Because of the 30 percent mulch cover, the effective canopy cover is only 0.70 of the overall 60 percent cover, or 42 percent. Entering figure IV.8 with a 42 percent canopy cover, we obtain a factor of 0.70 for canopy effect. The factor for this combination of canopy and mulch cover is the product of the two subfactors (0.47 times 0.70), which equals 0.33.

Residual Effects Of Land Use, Type III

This category includes residual effects of the land use on soil structure, organic matter content, and soil density; effects of site preparation or lack of preparation on surface roughness and porosity; roots and subsurface stems; biological effects; and any other factors affected by land use.

Figure IV.10 (Wischmeier 1975) was developed for Type III effects on undisturbed pasture, range, forest, and idle land. The initial point (0.45) for the curves is an estimate of the long-term effect of no tillage and no vegetation. It was obtained from 10-year soil loss records on a 12 percent slope of silt loam soil that was not tilled after the first year but was kept free of vegetation and traffic. The rate of soil loss per unit of EI declined annually until it leveled off at about 45 percent of the rate for the first 2 years of the study. The curvature and end-points of the curves were based on comparisons of soil losses from meadow with those from plots having equivalent percentages of surface cover in the form of applied straw mulch.

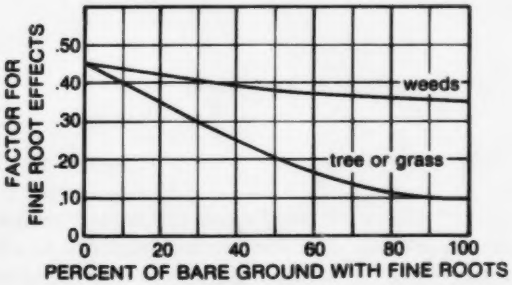


Figure IV.10.—Effects of fine roots in topsoil on the VM factor. These values do not apply to cropland and construction sites (Wischmeier 1975).

If an area has been cultivated or totally scalped so that all of the fine roots from trees, grass, and weeds are destroyed, then the Type III effect as described does not exist.

Sediment Filter Strips

Sediment filter strips are areas of residue or other kinds of effective sediment traps. If surface areas that are completely open (having minimal amounts of residue and soil mixed with residue) are separated from each other by small filter strips, a factor of 0.5 should be included in the calculations (Wischmeier 1972). If the open areas are not separated by sediment filter strips, use a factor of 1.0 (see example in Chapter VIII).

Determining The Vegetation-Management Factor

Use either previously published values or estimate the VM factor using Type I, II and III subfactors.

Previously published tables (tables IV.3, IV.4, IV.5, and IV.6) and graphs (figs. IV.11 and IV.12) are reproduced in this chapter with specific VM values for use under some conditions. Table IV.3 applies only to construction sites (e.g., roads). Tables from other literature are usually expressed in terms of the C factor for the Universal Soil Loss Equation. The C factor is considered appropriate only if the forest situation and the situation represented in the published tables have the following in common: the management practice described in the table must have the same characteristics as the one to be used, the vegetative recovery rates must be the same, and all assumptions must be the same in practice as presented in the tables. In addition there will be significant errors if terminology used in the tables does not mean exactly the same thing from one part of the country to another.

Type I, II, and III values determined from figures IV.8, IV.9, and IV.10 are multiplied to obtain a VM value for use in equation IV.1. An example of this procedure is given in chapter VIII.

This estimation procedure for VM does not recognize the effects of time on fine root-density. It is recognized that some changes in soil characteristics which influence erodibility will occur due to various silvicultural activities. If these soil changes are for a short time (only a few years),

Table IV.3.—VM factor values for construction sites (Clyde et al. 1976).

Condition	VM factor
1. Bare soil conditions	
freshly disked to 6-8 inches	1.00
after one rain	0.89
loose to 12 inches smooth	0.90
loose to 12 inches rough	0.80
compacted buldozer scraped up and down	1.30
same except root raked	1.20
compacted bulldozer scraped across slope	1.20
same except root raked across	0.90
rough irregular tracked all directions	0.90
seed and fertilize, fresh	0.64
same after six months	0.54
seed, fertilize, and 12 months chemical	0.38
not tilled algae crusted	0.01
tilled algae crusted	0.02
compacted fill	1.24
undisturbed except scraped	0.66-1.30
scarified only	0.76-1.31
sawdust 2 inches deep, disked in	0.61
2. Asphalt emulsion	
1,250 gallons/acre	0.02
1,210 gallons/acre	0.01-0.019
605 gallons/acre	0.14-0.57
302 gallons/acre	0.28-0.60
151 gallons/acre	0.65-0.70
3. Dust binder	
605 gallons/acre	1.05
1,210 gallons/acre	0.29-0.78
4. Other chemicals	
1,000 lb fiber glass roving with 60-150 gallons/acre	0.01-0.05
Aquatain	0.68
Aerospray 70, 10 percent cover	0.94
Curasol AE	0.30-0.48
Petroset SB	0.40-0.66
PVA	0.71-0.90
Terra-Tack	0.66
5. Seedlings	
temporary, 0 to 60 days	0.40
temporary, after 60 days	0.05
permanent, 0 to 60 days	0.40
permanent, 2 to 12 months	0.05
permanent, after 12 months	0.01
6. Brush	0.35
7. Excelsior blanket with plastic net	0.04-0.10

they are accounted for by the VM factor. Long-term changes in soil erodibility, as a result of activities changing soil structure and permeability, should be evaluated by changing the K factor.

Adjustments for surface microrelief or roughness and adjustments for different contouring practices are also lacking from this presentation. More research needs to be directed toward these additional VM subfactors.

Seasonal Adjustments For VM

If necessary, the VM factor can be adjusted for seasonal changes using equation IV.11 to obtain an average annual VM value.

$$VM = \frac{(VM_g M_g + VM_d M_d)}{M_g + M_d} \qquad (IV.11)$$

where:

VM = weighted mean vegetation-management factor,

VM_g = VM factor for growing season,

M_g = number of growing season months with erosive rainfall,

VM_d = VM factor for dormant season,

M_d = number of dormant months with erosive rainfall and/or snowmelt runoff.

Estimated Soil Loss Per Unit Area

When all of the parameters of the MSLE (equation IV.1) have been assigned the proper values, the factors are multiplied to obtain an estimate of soil loss for a specific unit area. The answer generally will be expressed in tons/acre/year. If other units of area and time are chosen for use in the MSLE, they must be applied consistently throughout the equation.

Converting MSLE To Metric[1]

The rainfall intensity-energy equation in the metric system is: $E = 210.3 + 89 \log_{10} i$ where E is kinetic energy in metric-ton meters/hectare/centimeter of rain, and i is rainfall intensity in centimeter/hour. A logical counterpart to the English-system EI is the product: storm energy in metric-ton meters/hectare times the maximum 30-minute intensity in centimeter/hour. The magnitude of this product would be 1.735 times that of the EI as defined in English units. The factor for direct conversion of K to metric-tons/hectare/metric EI units is 0.2572.

---

[1] The equations used in this chapter usually require data to be in the English system (inches, feet, lbs., etc.) with the exception of equation IV.10. Substitution of metric data without making appropriate changes in equation coefficients will result in erroneous answers.

Table IV.4.—"C" factors for permanent pasture, rangeland, idle land, and grazed woodland[1] (Soil Conservation Service 1977)

Vegetal canopy Type and height of raised canopy[2]	Canopy cover[3]	Type[4]	Cover that contacts the surface					
			Percent ground cover					
	%		0	20	40	60	80	95-100
No appreciable canopy		G	.45	.20	.10	.042	.013	.003
		W	.45	.24	.15	.090	.043	.011
Canopy of tall weeds or short brush (0.5 m fall ht.)	25	G	.36	.17	.09	.038	.012	.003
		W	.36	.20	.13	.082	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
	75	G	.17	.10	.06	.031	.011	.003
		W	.17	.12	.09	.067	.038	.011
Appreciable brush or bushes (2 m fall ht.)	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.085	.042	.011
	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.077	.040	.011
Trees but no appreciable low brush (4 m fall ht.)	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.087	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.085	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.083	.041	.011

---

[1] All values shown assume (1) random distribution of mulch or vegetation, and (2) mulch of appreciable depth where it exists. Idle land refers to land with undisturbed profiles for at least a period of three consecutive years. Also to be used for burned forest land and forest land that has been harvested less then 3 years ago.

[2] Average fall height of water drops from canopy to soil surface.

[3] Portion of total-area surface that would be hidden from view by canopy in a vertical projection (a bird's-eye view).

[4] G: Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 inches deep. W: Cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface), and/or undecayed residue.

Table IV.5.—"C" factors for undisturbed woodland (Soil Conservation Service 1977)

Effective canopy[1] % of area	Forest litter[2] % of area	"C"[3] factor
100-75	100-90	.0001-.001
70-40	85-75	.002-.004
35-20	70-40	.003-.009

---

[1] When effective canopy is less than 20 percent, the area will be considered as grassland or idle land for estimating soil loss. Where woodlands are being harvested or grazed, use table IV.4.

[2] Forest litter is assumed to be at least 2 inches deep over the percent ground surface area covered.

[3] The range in "C" values is due in part to the range in the percent area covered. In addition, the percent of effective canopy and its height has an effect. Low canopy is effective in reducing raindrop impact and in lowering the "C" factor. High canopy, over 13 m, is not effective in reducing raindrop impact and will have no effect on the "C" value.

Table IV.6.—"C" factors for mechanically prepared woodland sites (U.S. Department of Agriculture Soil Cons. Serv. 1977.)

Percent of soil covered with residue in contact with soil surface	**Soil Condition and Weed Cover**[4]							
	Excellent		**Good**		**Fair**		**Poor**	
	NC[5]	WC[5]	NC	WC	NC	WC	NC	WC
None								
A. Disked, raked or bedded[1 2]	.52	.20	.72	.27	.85	.32	.94	.36
B. Burned[3]	.25	.10	.26	.10	.31	.12	.45	.17
C. Drum chopped[3]	.16	.07	.17	.07	.20	.08	.29	.11
10% Cover								
A. Disked, raked or bedded[1 2]	.33	.15	.46	.20	.54	.24	.60	.26
B. Burned[3]	.23	.10	.24	.10	.26	.11	.36	.16
C. Drum chopped[3]	.15	.07	.16	.07	.17	.08	.23	.10
20% Cover								
A. Disked, raked or bedded[1 2]	.24	.12	.34	.17	.40	.20	.44	.22
B. Burned[3]	.19	.10	.19	.10	.21	.11	.27	.14
C. Drum choppd[3]	.12	.06	.12	.06	.14	.07	.18	.09
40% Cover								
A. Disked, raked or bedded[1 2]	.17	.11	.23	.14	.27	.17	.30	.19
B. Burned[3]	.14	.09	.14	.09	.15	.09	.17	.11
C. Drum chopped[3]	.09	.06	.09	.06	.10	.06	.11	.07
60% Cover								
A. Disked, raked or bedded[1 2]	.11	.08	.15	.11	.18	.14	.20	.15
B. Burned[3]	.08	.06	.09	.07	.10	.08	.11	.08
C. Drum chopped[3]	.06	.05	.06	.05	.07	.05	.07	.05
80% Cover								
A. Disked, raked or bedded[1 2]	.05	.04	.07	.06	.09	.08	.10	.09
B. Burned[3]	.04	.04	.05	.04	.05	.04	.06	.05
C. Drum chopped[3]	.03	.03	.03	.03	.03	.03	.04	.04

[1] Multiply A. values by following values to account for surface roughness:

Very rough, major effect on runoff and sediment storage, depressions greater than 6" 0.40
Moderate 0.65
Smooth, minor surface sediment storage, depressions less than 2" 0.90

[2] The "C" values for A. are for the first year following treatment. For A. type sites 1 to 4 years old, multiply "C" value by 0.7 to account for aging. For sites 4 to 8 years old, use table IV.4. For sites more than 8 years old, use table IV.5.

[3] The "C" values for B. and C. areas are for the first 3 years following treatment. For sites treated 3 to 8 years ago, use table IV.4. For sites treated more than 8 years ago, use table IV.5.

[4] Soil condition and weed cover descriptors.

Excellent—Highly stable soil aggregates in topsoil with litter and fine tree roots mixed in.

Good—Moderately stable soil aggregates in topsoil or highly stable soil aggregates in subsoil (topsoil removed during raking), only traces of litter mixed in.

Fair—Highly unstable soil aggregates in topsoil or moderately stable soil aggregates in subsoil, no litter mixed in.

Poor—No topsoil, highly erodible soil aggregates in subsoil, no litter mixed in.

[5] For each of the soil conditions, "C" factors are provided for no live vegetation (NC column) and for 75% cover of grass and weeds having about 0.5 meter fall height (WC column). For weed and grass cover other than 0% and 75%, "C" values may be interpolated.

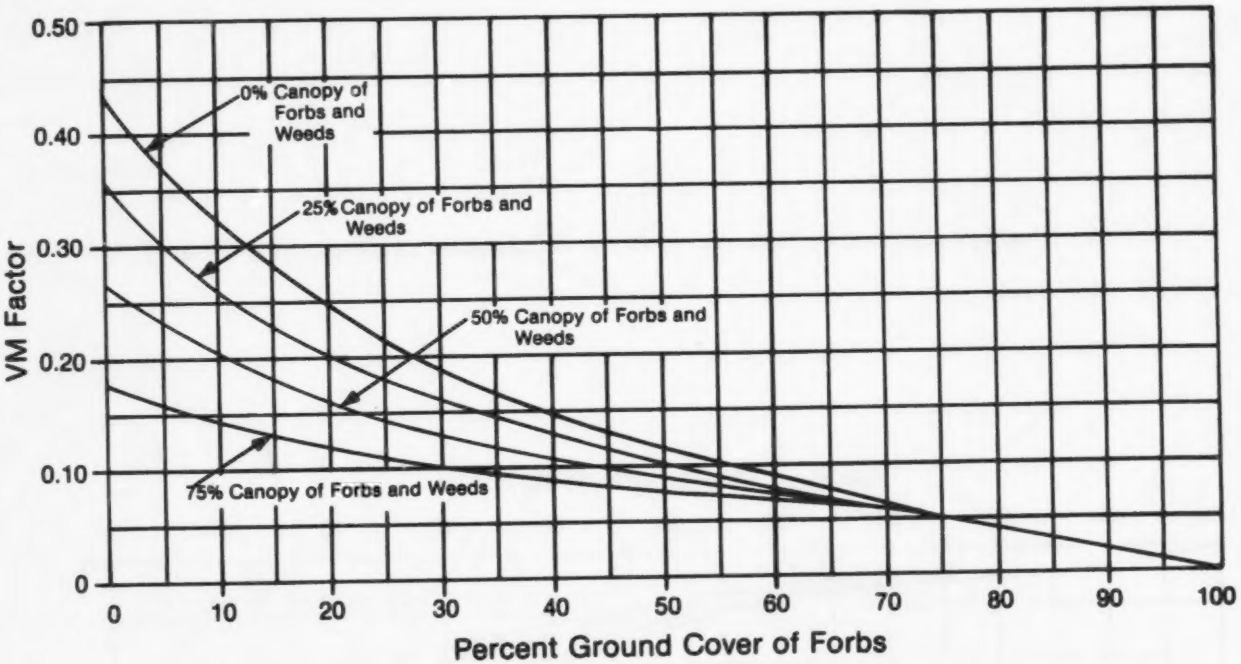


Figure IV.11—Relationship between grass density and the VM factor (Clyde and others 1976).

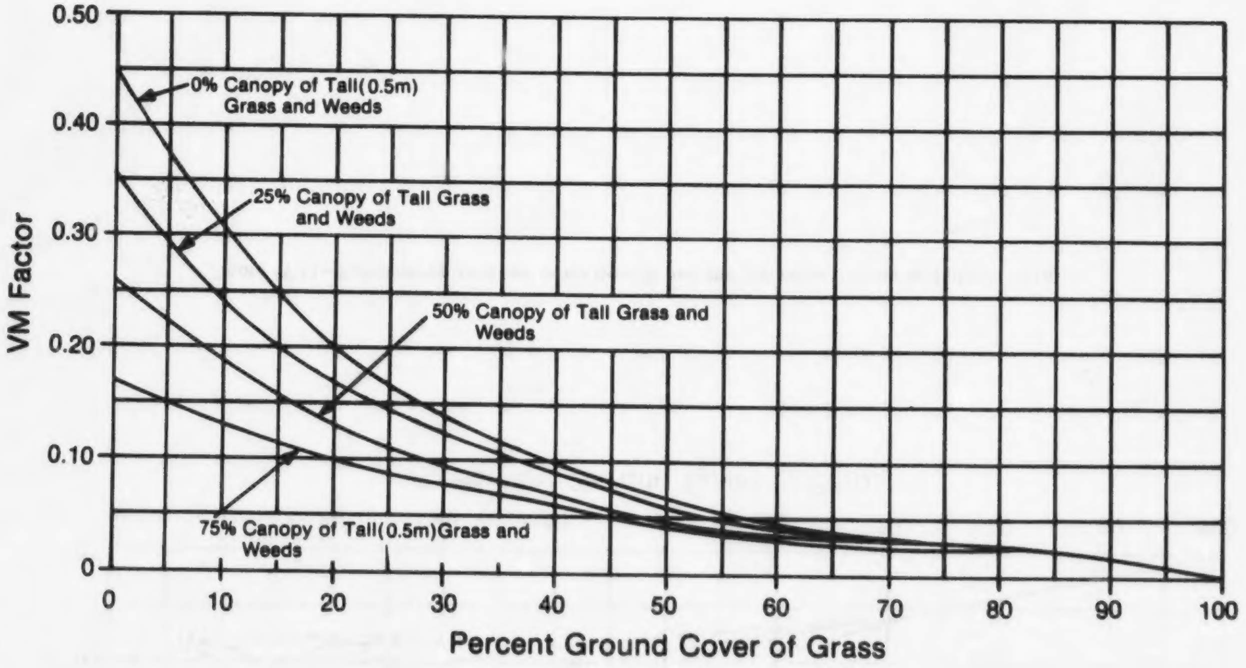


Figure IV.12—Relationship between forb density and the VM factor (Clyde and others 1976).

For practical purposes, it would be expedient to redefine the unit-plot as having a length of 25 meters and a slope of 10 percent, to derive K on the basis of those dimensions, and to recompute the slope-effect chart. The translated values would be:

L = $\lambda^{0.5}/_5$ where λ is slope length in meters; and $S = (0.43 + 0.30s + 0.043s^2)7.73$ where, s = percent slope. Combining the two,

LS = $\sqrt{\lambda}(0.00111s^2 + 0.00776s + 0.0111)$. (Wischmeier 1972).

Erosion Response Units

Potential sources of non-point pollution constitute site specific problems within an individual watershed. To estimate the magnitude of a specific onsite soil loss and to identify the particular drainageway where this erosion occurs, the watershed must be divided into homogeneous areas. Delineating erosion response units requires identification of individual activities such as roads, landings, cutting blocks, or skid trails, and the relative contribution of each activity to potential sediment yield.

Delineating Erosion Response Units

The following information needs to be shown on a series of maps or overlays in order to identify and delineate erosion response units:

1. Topographic information showing hydrographic areas and channel network.
2. Soil and vegetative resource information used for the quantification of surface erosion.
3. Project proposal showing the location of roads, trails, landings, cutting units, etc.

The procedure for compiling these data is explained by steps:

Step 1. — Obtain a topographic map (fig. IV.13) to show spatial relationships of the factors needed in the quantification process. The amount of detail desired and the amount that can be produced by the analysis will depend upon the scale and accuracy of the base map.

Step 2. — Extend the stream detail shown on the topographic base (fig. IV.14). Perennial streams, and in some cases intermittent streams, will be printed on the original topographic base; however, this does not completely define the stream channel network within that watershed. It is important that the displayed stream network be extended to include all intermittent channels that are definable on the basis of the contour lines. Each channel should be extended toward the watershed divide from channels originally identified on the base map. Field information, if available, should be used to verify the final channel network.

Step 3. — Delineate individual hydrographic areas (fig. IV.15). Draw the interior watershed boundaries or hydrographic divides separating the extended channel network that was identified in step 2. At this point, a series of sub-watersheds or hydrographic areas will have been delineated within the watershed of interest.

Step 4. — Since soils information is required for the evaluation of onsite erosion, soil mapping unit boundaries should be drawn (fig. IV.16). These soil units may come from a standard soil survey, a soil resource inventory, or a land systems inventory. The soils may be grouped so that the delineated map units represent soils that are homogenous with respect to texture (percent sand, silt, clay), organic matter, permeability, and structure. Vegetative cover information, if available, should be mapped to show the percent surface area occupied by vegetation, mulch, rock, litter, and debris. Sediment delivery, as well as surface erosion, is greatly influenced by these factors; having them mapped prior to initiating quantification of erosion is beneficial to the analysis.

For the purpose of bookkeeping, it is necessary to number these erosion response units consecutively. Begin near the mouth of the watershed with number "1" and proceed clockwise toward the head of the watershed and back around the mouth on the opposite side.

Step 5. — Stratify the problem as it relates to the proposed silvicultural activity by drawing roads, cutting blocks, log landings, skid trails, and other activities on an overlay for the topographic base (fig. IV.17). Placing this information on an overlay will make the maps more readable and will also facilitate making changes in a proposal without destroying the entire topographic base.

Delineate the transportation system first, including all existing and proposed roads, skid trails, and aircraft landing areas. Then delineate the cutting blocks as precisely as possible relative to the topographic base (fig. IV.18). Other items, such as decking areas and log landings, should also be shown on the topographic base whenever possible. Once again, the detail that is shown will partially determine the detail of the analysis.

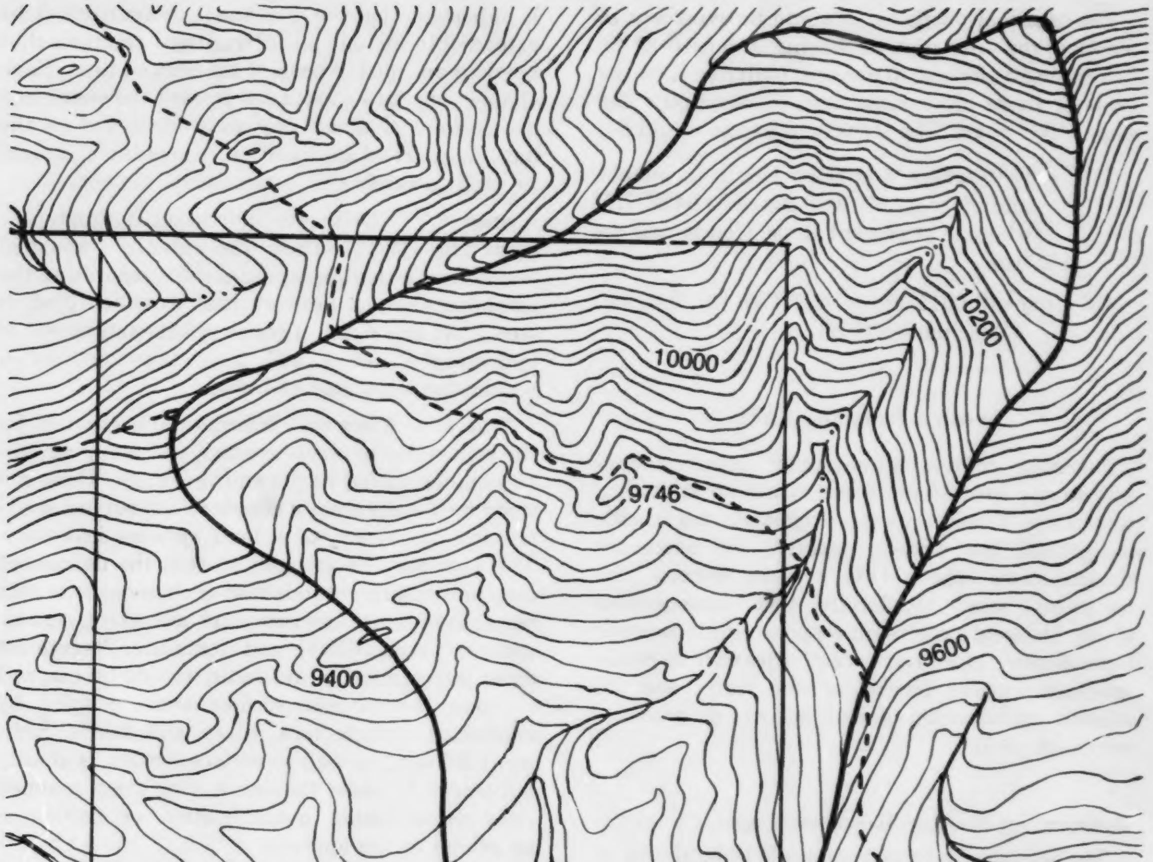


Figure IV.13.—The Horse Creek watershed boundary.

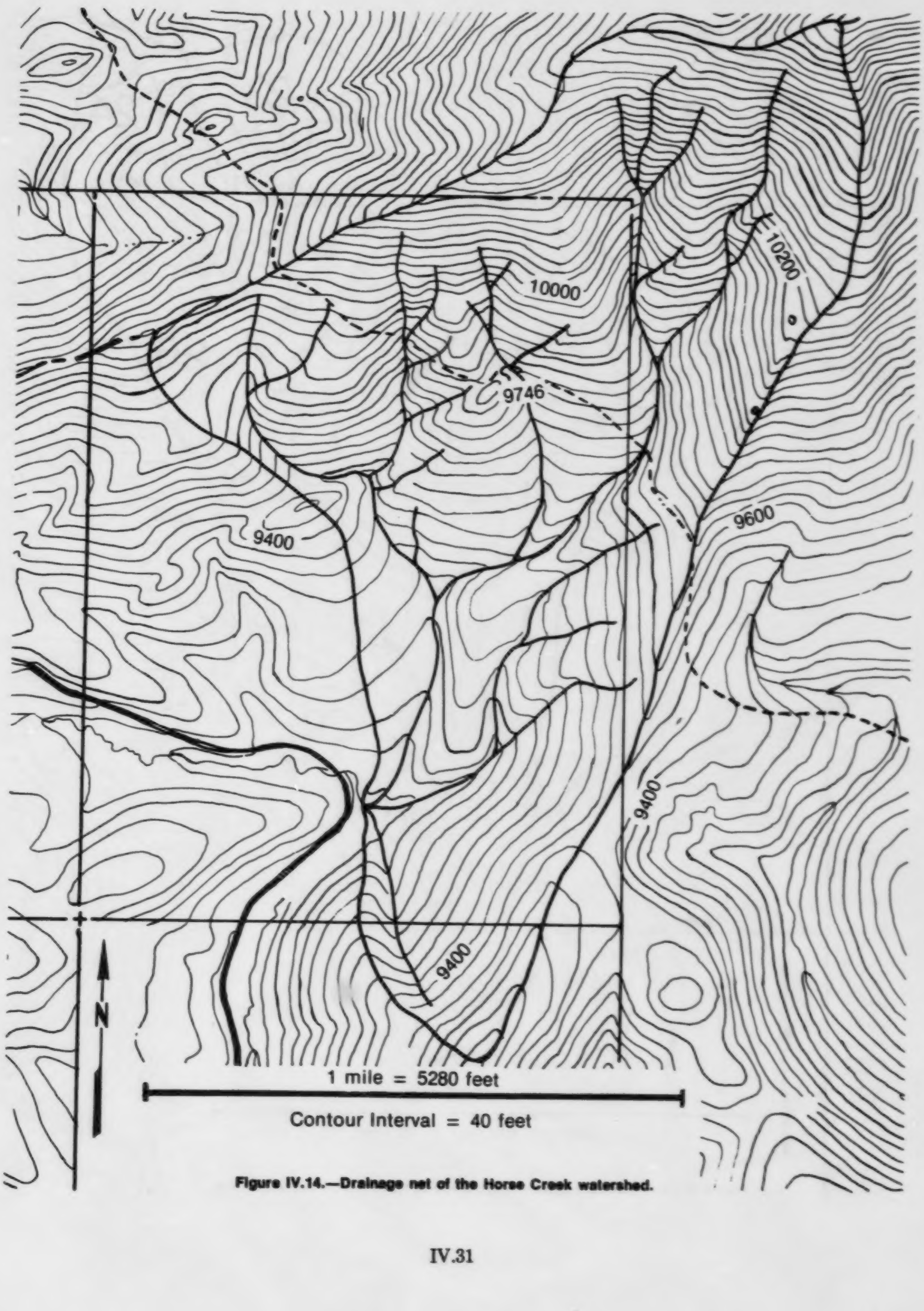


Figure IV.14.—Drainage net of the Horse Creek watershed.

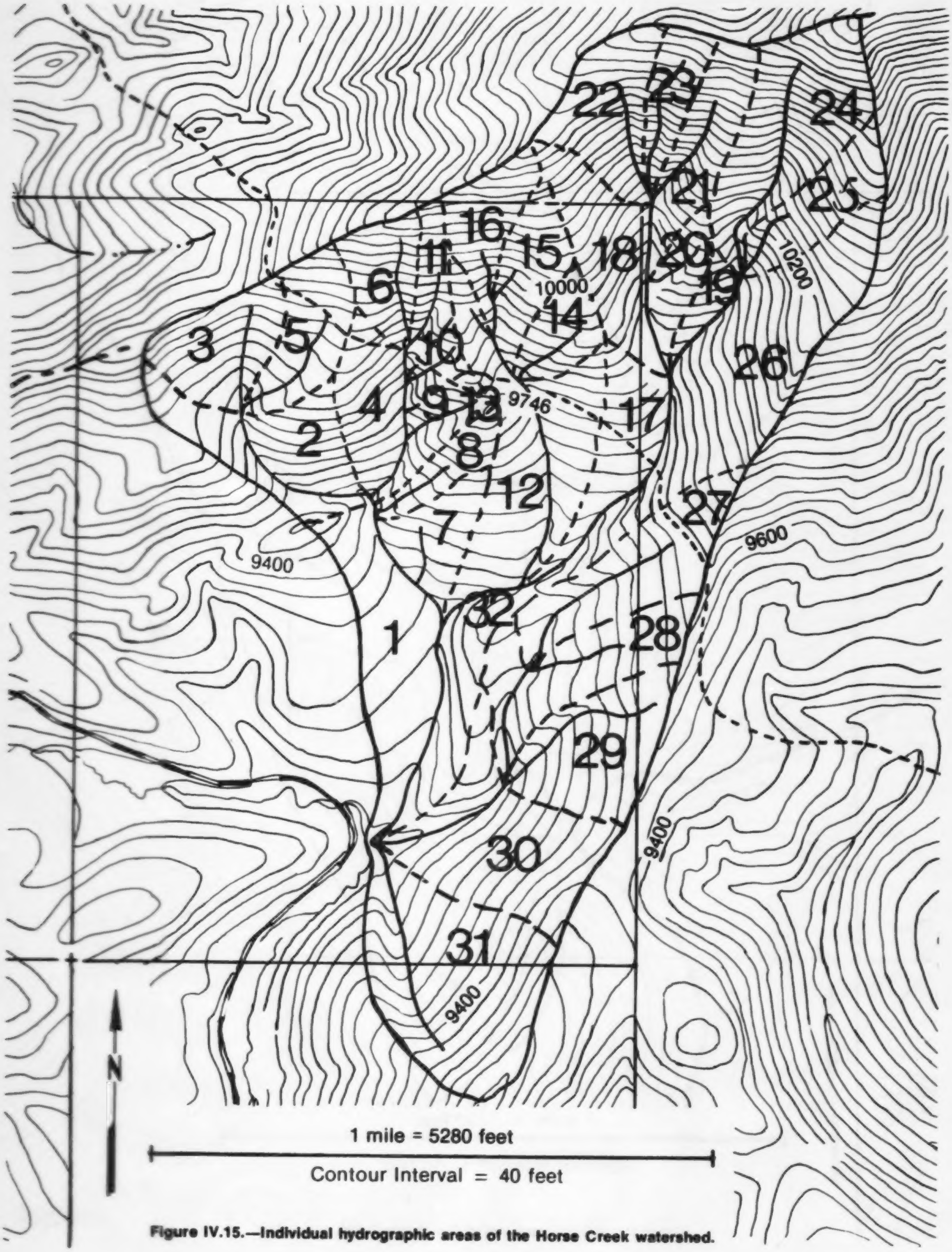


Figure IV.15.—Individual hydrographic areas of the Horse Creek watershed.

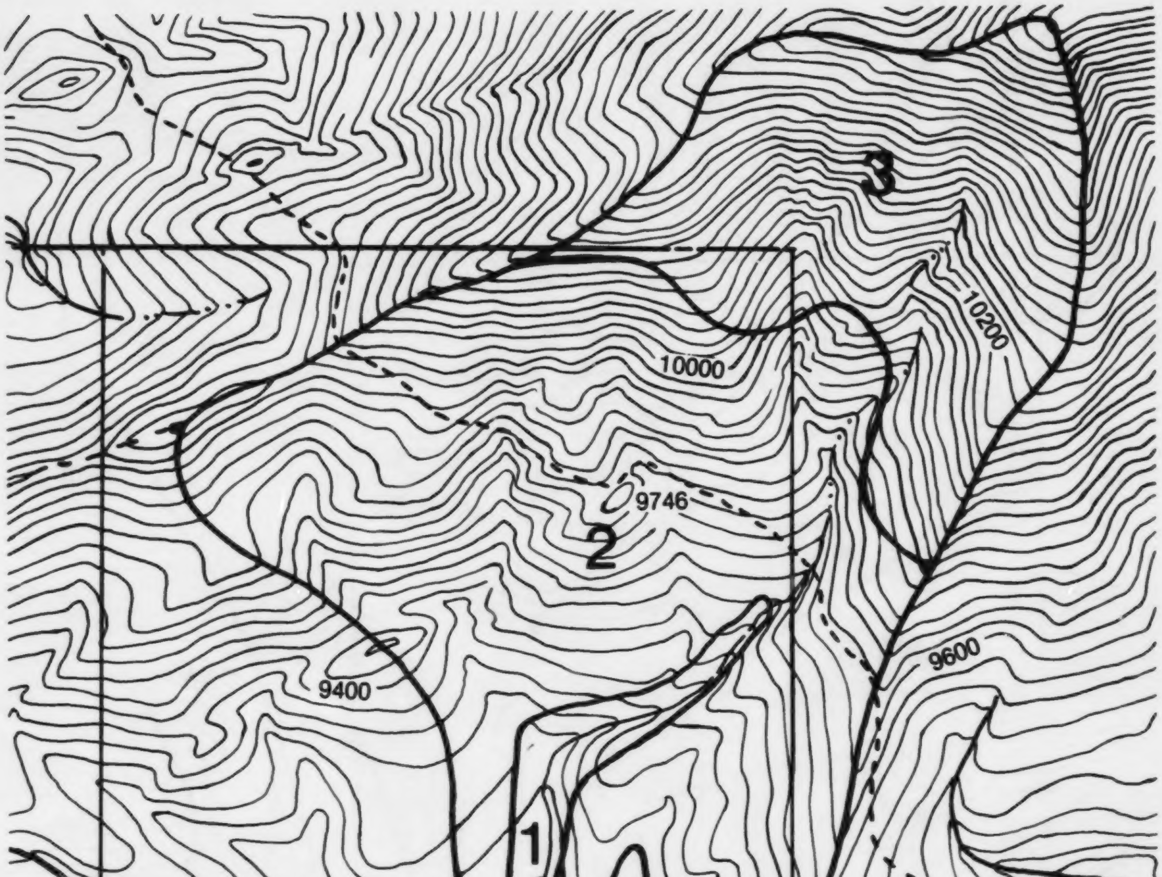


Figure IV.16.—Soil mapping unit boundaries for the Horse Creek watershed.

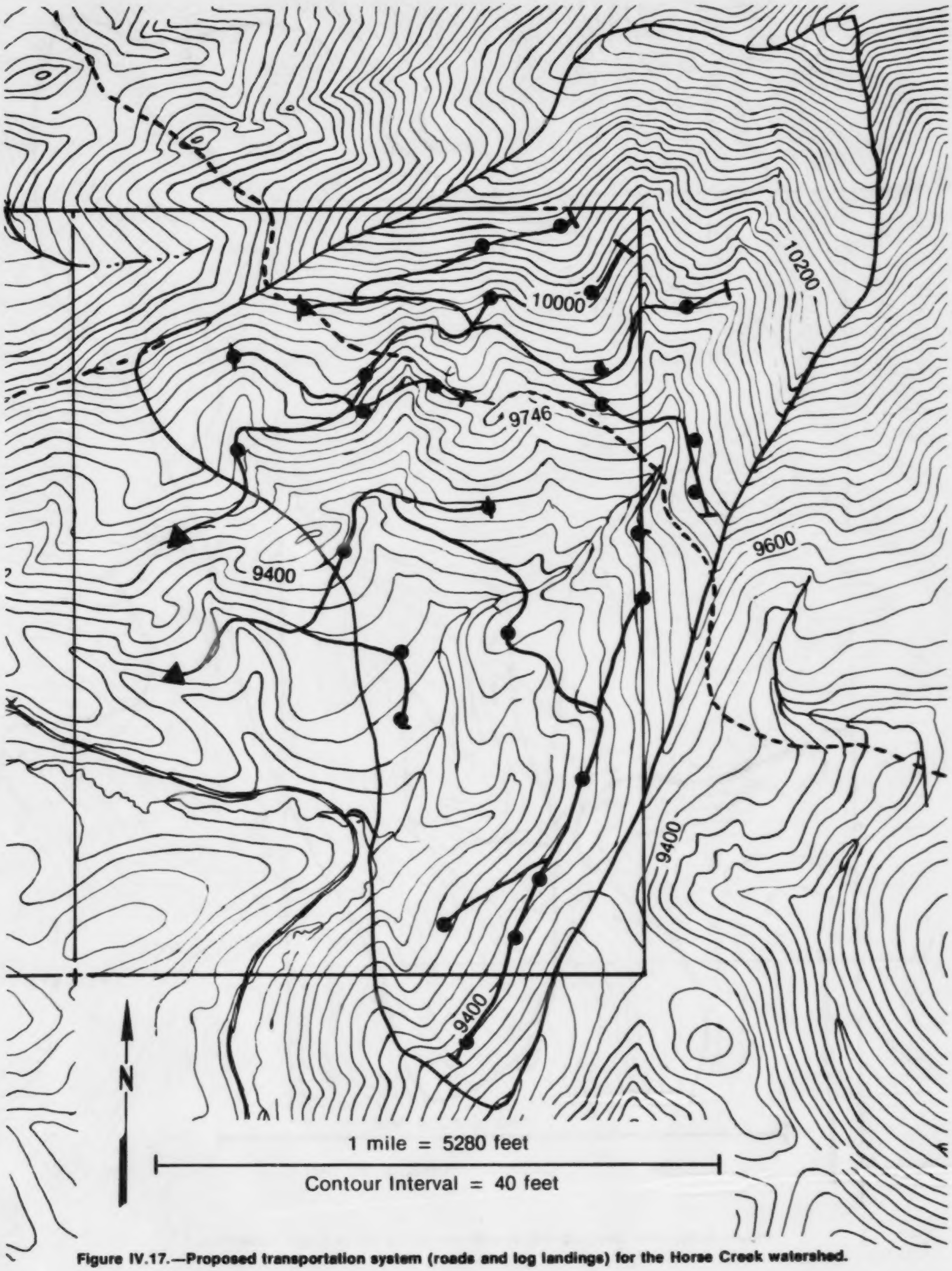


Figure IV.17.—Proposed transportation system (roads and log landings) for the Horse Creek watershed.

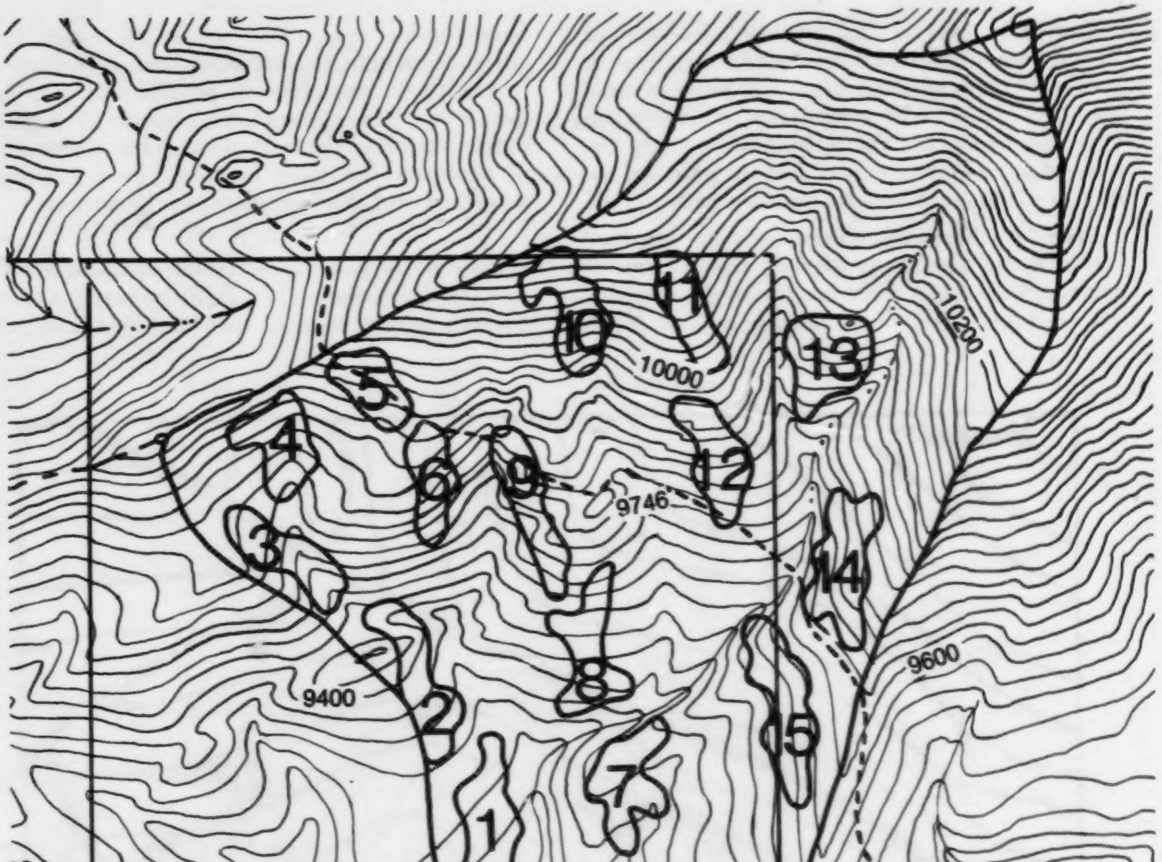


Figure IV.18.—Proposed cutting units for the Horse Creek watershed.

Step 6. — All of the preceding information should be incorporated onto a single map base or preferably onto overlays using the previous map scale (fig. IV.19). The information in its overlaid form should include the hydrographic areas, the soil and vegetation resources, and the proposed activities within each erosion response unit.

Step 7. — Further subdivisions of the proposed activities are possible to identify specific sources contributing eroded materials to the drainageway via separate delivery routes within each hydrographic area. The degree to which the silvicultural activities are subdivided is important to the final quantification process and may be useful in ultimately applying controls to specific parts of an area. The more detailed the subdivision of activities the more complex the accounting procedure and the more detailed the answer.

Step 8. — List the potential sediment source areas on worksheets (IV.1-IV.8) by activity types for each erosion response unit identified in step 4.

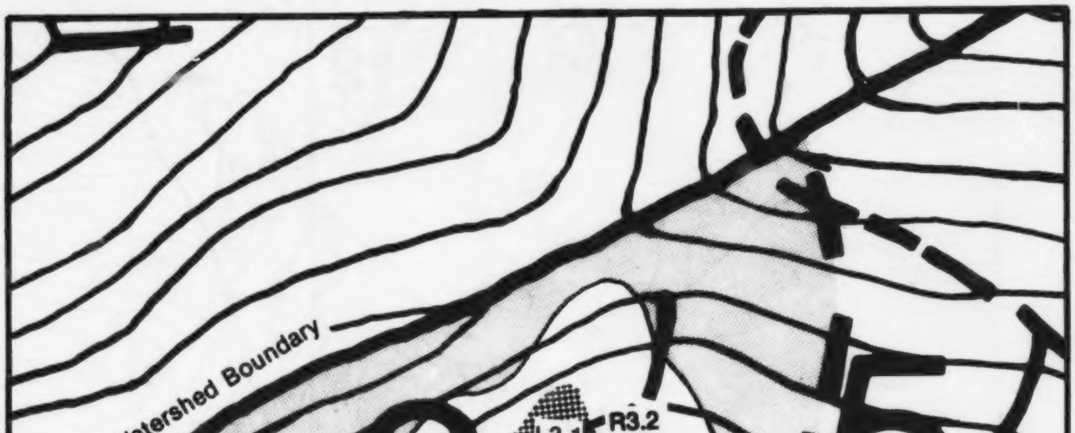


Figure IV.19.—Composite map of all topographic and management treatments for the Horse Creek watershed, hydrographic area 3.

WORKSHEET IV.1

Soil characteristics for the _____________________ watershed

Soil group		Percent sand 2.0-0.1 mm	Percent very fine sand 0.10-0.05 mm	Percent "coarse silt" 0.062-0.05 mm[1/]	Percent silt 0.05-0.002 mm	Percent clay 0.002 mm	Percent organic matter	Soil structure		Soil permeability	
								MSLE code	Descrip- tive	MSLE code	Inches per hour
1	Topsoil										
	Subsoil										
2	Topsoil										
	Subsoil										
3	Topsoil										
	Subsoil										

[1/] The "coarse silt" particle size group is not part of the USDA classification system, but 0.062 mm represents an upper limit of particle size that is used when estimating suspended sediment transport in streams. For this use only the "coarse silt" size within the USDA very fine sand classification is presented.

WORKSHEET IV.2

__________ watershed erosion response unit management data for use in the MSLE and sediment delivery index, hydrographic area __________

Erosion response unit	Slope length of disturbed area (ft)	Slope gradient of disturbed area (%)	Length of road section (ft)	Average width of disturbance (ft)	Area (sq.ft.)	Area (acres)
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						
11.						
12.						
13.						
14.						
15.						
16.						
17.						
18.						
19.						
20.						
21.						
22.						
23.						
24.						
25.						

2 of 3

WORKSHEET IV.2--continued

	Area with surface residues			Open area				
	Percent of total area	Percent of surface with mulch	Percent of area with fine roots	Percent of total area	Percent of surface with mulch	Percent of area with fine roots	Are open areas separated by filter strips?	Percent of total area with canopy
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								
9.								
10.								
11.								
12.								
13.								
14.								
15.								
16.								
17.								
18.								
19.								
20.								
21.								
22.								
23.								
24.								
25.								

3 of 3

WORKSHEET IV.2--continued

Average minimum height of canopy (m)	Time for recovery (mo)	Average dist. from disturbance to stream channel (ft)	Overall slope shape between disturbance and channel	Percent ground cover in filter strip	Surface roughness (qualitative)	Texture of eroded material (% silt + clay)	Percent slope between disturbance and channel
1.							
2.							
3.							
4.							
5.							
6.							
7.							
8.							
9.							
10.							
11.							
12.							
13.							
14.							
15.							
16.							
17.							
18.							
19.							
20.							
21.							
22.							
23.							
24.							
25.							

WORKSHEET IV.3

Estimates of soil loss and delivered sediment by erosion response unit
for hydrographic area ________ of ________________________ watershed

Erosion response unit	Soil unit	R	K	LS	VM	Area (acres)	Surface soil loss (tons/yr)	SD_I	Delivered sediment (tons/yr)

WORKSHEET IV.4

Estimated VM factors for silvicultural erosion response units
____________________ watershed, hydrographic area ________

Logging residue area						Open area						
Erosion response unit	Fraction of total area	Mulch (duff & residue)	Canopy	Roots	Sub VM	Fraction percent of total area	Mulch (duff & residue)	Canopy	Roots	Filter strip	Sub VM	Total VM

WORKSHEET IV.5

Example of estimated monthly change in VM factor following construction for road cuts and fills in ________________ watershed, hydrographic area ____________________________

Month	Percent cover and VM subfactors						Monthly VM
	Mulch		Canopy		Roots		
	Percent	VM	Percent	VM	Percent	VM	
Sep.[1]							
Oct.[3]							
Nov.							
Dec.[2]							
Jan.[2]							
Feb.[2]							
March[2]							
April[4]							
May[4]							
June[5]							
July[5]							
Aug.							

[1] Begin seeding, enough rain is assumed to ensure seed germination.

[2] Snow cover with no erosive precipitation.

[3] Significant canopy effect developing.

[4] Snowmelt runoff occurs, some protective vegetative cover lost during winter.

[5] Significant root network developing from seeded grass.

WORKSHEET IV.6

Weighting of VM values for roads in

__________________ watershed, hydrographic area _____

	Cut or fill		Roadbed		Fill		Weighted
Erosion response unit	Fraction of total width	VM	Fraction of total width	VM	Fraction of total width	VM	VM

WORKSHEET IV.7

Factors for sediment delivery index from erosion response units in

______________________ watershed, hydrographic area _________

Erosion response unit	Water availability	Texture of eroded material	Percent ground cover between disturbance and channel	Slope shape code	Distance (edge of disturbance to channel) (ft)	Surface roughness code	Slope gradient (%)	Specific site factor	Percent of total area for polygon	SD$_i$

WORKSHEET IV.8

Estimated tons of sediment delivered to a channel for each hydrographic area and type of disturbance for ____________________ watershed

____

Hydrographic area	Cutting units					Landings			Roads					Total tons/yr	Percent
	CC_1	CC_2	CC_3	CC_4	CC_5	L_1	L_2	L_3	R_1	R_2	R_3	R_4	R_5		
Column total															
Disturbance total															
Percent															

Summary

Once the data are accumulated, a specific estimate of surface soil loss can be made. To compute an estimate of total soil loss for a unit area (one acre), the MSLE must be applied to each activity within the area. The unit area soil loss is multiplied by the actual area that is disturbed by an activity to obtain an estimate of surface soil loss per activity. Soil loss for each activity is then added together to obtain estimated total soil loss. This overall procedure is further explained in "The Procedure" section of this chapter.

CONSIDERATIONS FOR REDUCING EROSION

Theoretically, it is possible to reduce soil loss by making appropriate changes in any of the MSLE factors. In actual practice, some factors are easier to change than others. The following tabulation describes the basic concepts underlying the variable changes brought about by controls for surface erosion. This conceptual presentation is to aid in understanding controls and determining which control practice to use. Details of specific control practices may be found in "Chapter II: Control Opportunities."

MSLE Factor	Preventive	Mitigative
R	Where soils have high erodibility factors, plan silvicultural activities so that snowmelt rates are not increased over natural conditions. Use management techniques which will not create significant increases in the amount of solar energy reaching the forest floor.	Reduce snowmelt runoff rates by intercepting the solar energy above the snow surface.
R	Control over the rainfall portion of the R factor is not likely to occur because it is a function of overall weather patterns.	
K	Use management practices that do not reduce long-term soil permeability, structure, or organic matter content. For example, avoid soil compaction or creation of conditions that destroy organic matter.	Increase long-term organic matter content in the soil by promoting good vegetative growth. This can lead to desirable soil structure and permeability. Obtaining desirable soil texture changes would be very difficult at best.
LS	Usually slope length and slope gradient effects must be considered together because a change in one also causes a change in the other.	
L	Control location and design of various types of construction to avoid creating long cut and/or fill slopes, large landings, and extensive activity areas.	Locate various types of diversions, such as terraces, to reduce the distance water can move over land.
S	Control location and design of various types of construction and other activities on steep slopes.	Reduce steep slopes, created by construction activities, by placing soil and rock at the base of a cut slope and removing it from a fill slope.
VM	Control and design forest activities to minimize forest floor destruction. Maintain adequate amounts of low understory canopy. This is important where surface residues are few or lacking. A high overstory canopy may accelerate raindrop splash erosion from storms in areas where the forest floor has been destroyed. An example might be a campground with little or no surface residue or understory canopy. Control the use and intensity of fire on coarse-textured soils to prevent hydrophobic conditions from developing.	Add mulch, or chemical binders, establish vegetation, or use other practices to change VM so that acceptable levels of soil loss are achieved. Use various mechanical methods of creating surface roughness or small diversions, e.g., perform final site preparation on the contour rather than up and down slope. Use wetting agents to reduce or reverse hydrophobic conditions enough to significantly reduce soil loss (Osborn and others 1964).

APPLICATIONS, LIMITATIONS AND PRECAUTIONS: SURFACE SOIL LOSS

The confidence limits on predictions by the Universal Soil Loss Equation are the narrowest (predictions are most accurate) for silt, silt loam, and loam textures on uniform slopes of 5 to 12 percent, and with slope lengths of less than 400 feet (122m) (Wischmeier 1972). **Beyond these limits, significant extrapolation errors become more likely.** However, the MSLE appears to have sufficient accuracy for comparing estimated soil loss from different silvicultural management practices on a given site over a wider range of forest environmental conditions. Predicting long-term (5- to 50-year) average soil loss for a given situation is limited by lack of available data needed to evaluate the individual terms rather than the overall model. The prediction accuracy for forest land may improve as research provides a more accurate evaluation of the critical site factors over a wider range of conditions within the forest environment.

Specific limitations of the MSLE are as follows:

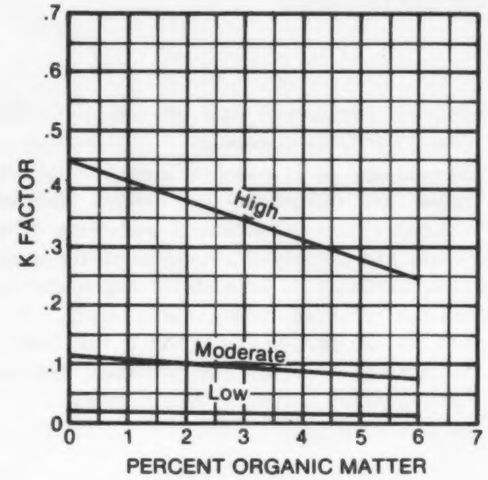
1. The MSLE is empirical; it indexes the quantity of soil loss under various forest conditions and does not always show the factors in correct relationships with actual erosion processes. There are limitations due to the use of empirical coefficients and fitted curves.
2. The MSLE only estimates an amount of soil loss, but does not deal with the probability or chance of soil loss occurring.
3. The MSLE was developed to predict soil loss on an average annual basis. Soil loss predictions on a storm-by-storm basis often are erroneous because of the complicated interaction between forces governing soil loss rates that are not accounted for by the MSLE. On any given site, these interactions may tend to average out over long periods of time so that their effect on long-term soil loss may be minimal. The soil loss equation has been rewritten in several attempts to develop techniques to handle storm-by-storm losses (Foster and others 1977, Williams 1975c, Williams and LaSeur 1976). The accuracy and reliability of such techniques is questionable, and it is not recommended that they be used for quantification.
4. It is assumed in the MSLE that the K factor is a constant, average value throughout a given analysis time period. However, changes in surface particle size distribution (texture) due to freeze-thaw or ongoing erosion processes will affect the value of K. Some of these effects, if they are short-term, are provided for by the VM factor. Long-term changes in the K factor due to soil compaction which occurs on roads, from equipment operations, or by animal traffic needs further study.
5. The LS factor has a low level of sensitivity to potential errors in the estimation of slope length because it is raised to a fractional power. However, an error in slope gradient, particularly on steep slopes, can result in a large error in LS because of the parabolic form of the equation.
6. The MSLE is most accurate for VM values above 0.2. As VM approaches 0.01 and below, the errors in the absolute estimate of soil loss increase greatly; the smaller VM becomes, the larger the potential absolute error.
7. The rainfall erosion index (R) measures only the erosive force of rainfall and associated runoff. The equation does not predict soil loss that is due solely to thaw, snowmelt, or wind.
8. Relationships of a given MSLE parameter to soil loss are often appreciably influenced by the levels of all other MSLE parameters (Wischmeier 1976). Graphs in figure IV.20 illustrate one example of this interrelationship for the K factor. Table IV.7 shows values used as constants in this example. Using figure IV.20 and table IV.7 together it is shown how changing one parameter, while holding all others constant (either at high, moderate, or low levels), affects erodibility, the K factor. For example, Figure IV.20a illustrates the effects upon the K factor when organic matter is varied from 0 to 6 percent and all other parameters are held constant. When all other parameters are at low or moderate levels, changes in organic matter do not appreciably affect erodibility. However, when all other parameters are held

Table IV.7.—Values of organic matter, fine sand + silt, clay, structure, and permeability used as constants when calculating K factor over a range of each parameter for low, moderate, and high values of K.

	Relative Level of K		
	Low	Moderate	High
% organic matter	6	3	0
% fine sand + silt	10	35	70
% clay	90	65	30
structure	4	3	1
permeability	1	3	6

at high levels, changes in organic matter do have an appreciable influence on the K factor. There is a similar graph for each of the K factor parameters showing the changes in K due to a change in a parameter.

9. There are additional erosion processes not accounted for in the MSLE that are important in making accurate predictions of soil loss. On steep slopes wind is an important erosion factor and may increase rainstorm erosion by up to one order of magnitude. Fall freeze-thaw processes cause a change in the median particle size of eroded material (Megahan 1978).
10. No adjustments are made for timing of rainfall relative to vegetative growth periods. Intuitively, the amount of soil loss would be different if most of the rainfall occurred during a vegetative dormant season rather than a growing period.
11. The MSLE does not separate runoff and rainfall components of erosion. If this could be done, the accuracy of estimated soil losses might be improved in situations where one factor is more important than the other.
12. There does not appear to be any acceptable method to account for the influence of rock and stone on the soil surface. A suggestion is to view the rock or stone as a non-erodible part of the surface; however, because of the runoff from the surface of a rock, there might be more soil loss than would occur without any rock.
13. Coarse-textured soils that are exposed to an intense fire may become hydrophobic, thus promoting more surface runoff after a fire than might have occurred under natural vegetation. It is not known if adjusting the K factor for a change in permeability will provide a satisfactory estimate of this effect on runoff-induced erosion.
14. The equation does not account for sediment deposition that occurs in depressions within a field, at the toe of a slope, along disturbance boundaries, or in terrace channels on a slope (Wischmeier 1976).
15. Gully erosion cannot be accounted for by the Modified Soil Loss Equation. (See appendix IV.A). The use of the soil loss equation is confined to sheet and rill erosion.
16. The relationships of factors influencing erosion on soils that are high in organic matter, that have developed from volcanic ash, or that have permafrost are not well understood. Use of the soil loss equation for these soils may result in significant errors in the amount of predicted soil loss.
17. The MSLE estimates average soil loss for 1 year only. Using MSLE for periods of over a year is briefly discussed in appendix IV.B.
18. Accurate soil loss estimates from roads and skid trails may not be obtained where they intercept surface and subsurface runoff in addition to precipitation. The MSLE does not estimate soil loss by concentrated water flow, such as in a road ditch. (See Appendix IV.C: Controlling Ditch Erosion).
19. In forest areas with a dense overstory canopy, there is a limit to map accuracy. When a topographic map is prepared from aerial photographs, the technician making the map cannot see the actual ground surface on the photograph — only the canopy top. The map maker is usually not acquainted with the area, but must still estimate the canopy height. Anything that would cause some trees to grow taller than others will cause errors in delineating contour lines. For example, a small first-order stream channel with its additional moisture may cause trees to grow so that the tops are level with tree tops on the drier interflueves between channels, and thus be mapped as a uniform ground surface.



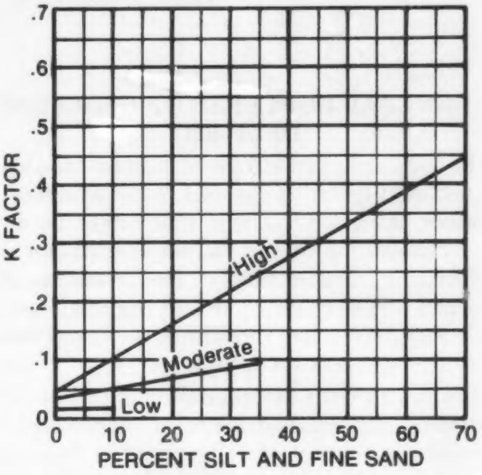


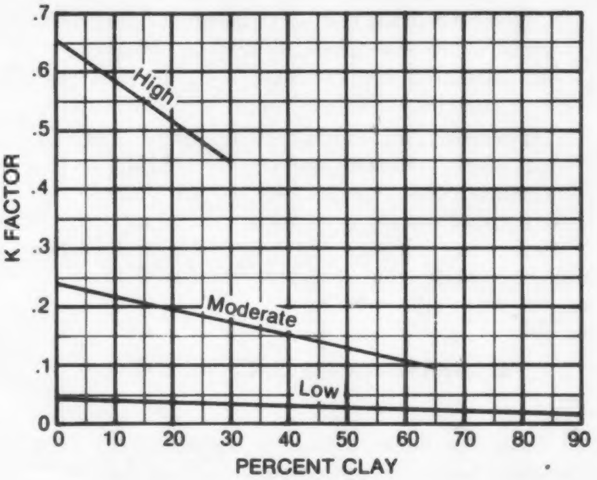
Figure IV.20a.—Effect of organic matter content on K factor when other parameters are at low, moderate, or high values.

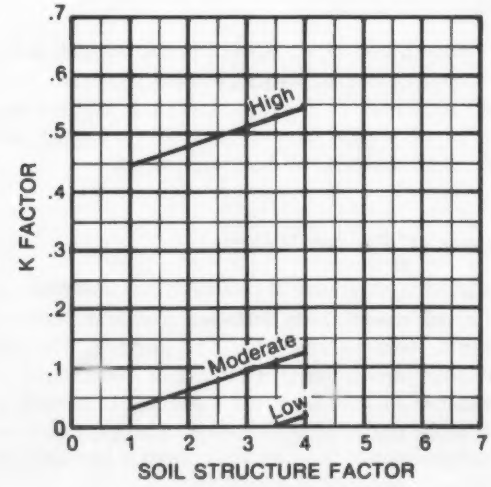
Figure IV.20b.—Effect of silt and fine sand on K factor when other parameters are at low, moderate, or high values.

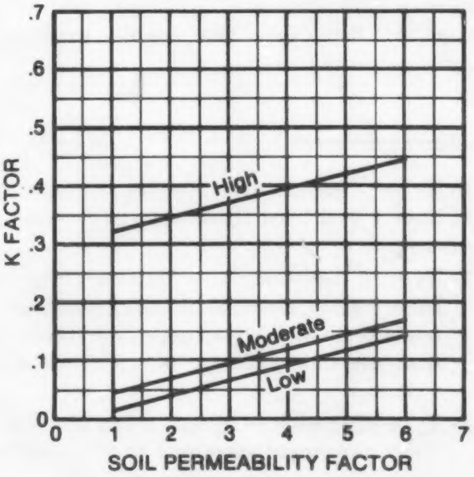
Figure IV.20c.—Effect of clay on K factor when other parameters are at low, moderate, or high values.

Figure IV.20d.—Effect of soil structure on K factor when other parameters are at low, moderate, or high values.

Figure IV.20e.—Effect of soil permeability on the K factor when other parameters are at low, moderate, or high values.







DISCUSSION: SEDIMENT DELIVERY

GENERAL CONCEPTS OF SEDIMENT DELIVERY

To evaluate the effects of surface erosion on water quality, it is necessary to estimate the amount of eroded material that might be moved from the eroding site into a receiving stream channel system. Unfortunately, the processes which describe the delivery of eroded materials are less well understood than those for erosion, and data for sediment delivery are scarce.

Historically, the determination of the amount of sediment that reached a stream channel revolved around the concept of delivery ratios (Gottschalk and Brune 1950, Maner 1958, Maner and Barnes 1953, Roehl 1962, Williams and Berndt 1972). A delivery ratio is the volume of material delivered to a point in the watershed, divided by the gross erosion estimated for the slopes in the watershed above that point. Values range from zero to one.

Apparently, a characteristic relationship of sediment yield to erosion does not exist. Many factors influence a sediment delivery ratio; if these factors are not uniform from one watershed to another, the relationship between sediment yield and erosion shows considerable variation (Renfro 1975).

Factors Influencing Sediment Delivery

Sediment delivery from a disturbed site to a stream channel is influenced to varying degrees by the following factors (Foster and Meyer 1977, Megahan 1974, Renfro 1975). (There may be other factors, not listed here, that are also important in given situations.)

Sediment Sources

In terms of effects upon a sediment delivery index, there are at least three ways to describe sediment sources:

1. Type of disturbance — Materials originating from logging areas, skid trails, landings, and roads seem to have a range of delivery ratios that are characteristic of each disturbance type.
2. Type of erosion — Sheet, rill, gully, and soil mass movement have one or more sediment delivery parameters that are unique to that particular form of erosion.
3. Mineralogy of the source area — Delivery ratios are influenced by various physical characteristics of sediment materials. Size, shape, and density of individual particles and their tendency to form stable aggregates are usually reflected by their mineralogy. Wettability of particles may be a function of mineralogy or of unique biological systems both of which influence the efficiency of sediment delivery.

Amount Of Sediment

When the amount of potential sediment exceeds the runoff delivery capability, deposition occurs and the amount of sediment delivered to a stream channel is closely controlled by the amount of runoff energy. If the amount of sediment is less than the runoff delivery capability, then no deposition will occur between the disturbed area and a stream channel.

Proximity Of Sediment Source

The distance that sediment must move and the shape and surface area of the transport path all affect the amount of material that may be lost from the transport system.

Transport Agents

Surface runoff from rainfall and snowmelt is the main agent for transporting eroded material. Sediment transport is dependent on the volume and velocity of water as well as the character and amount of material to be transported.

Texture Of Eroded Material

Individual particles of fine-textured material can be moved easier than particles of coarse-textured material because the finer the particle, the less transport energy required. If a watershed is dominated by fine-textured material, it is likely to have more material delivered to a stream channel by surface runoff than an equivalent situation with coarse-textured material — assuming that soil aggregates are not involved.

Deposition Areas

Microrelief that results in surface depressions or other irregularities will deliver less sediment than a smooth, flat surface. Decreases in slope gradient also promote deposition of large size fractions of transported material.

Watershed Topography

Size of the drainage area, overall shape of the land surface, (concave to convex), slope gradient, slope length, and stream channel density all affect the sediment delivery ratio by varying amounts.

Sediment Delivery Model

From the previous discussion concerning factors that influence sediment delivery over an area of land, it can be seen that the amount of eroded material deposited between a disturbed site and a drainage channel is due to a variety of interacting factors. To aid understanding overland sediment transport, the process can be divided conceptually into two parts.

The first requirement is a transporting agent with sufficient energy to move the sediment. In this case, surface runoff is the transporting agent. Its energy is a function of the amount and velocity of waterflow passing over a given area in a given time period.

The second part deals with factors which tend to stop or slow the movement of sediment and waterflow over a slope. Microrelief, slope gradient, slope length, slope shape, vegetation, and surface residues all play a part in reducing the amount of sediment that will actually reach a delivery point (Neibling and Foster 1977, Zingg 1940).

The shape of the area over which sediment is transported (fig. IV.21) also influences the amount actually delivered to a drainage channel. In one case, sediment entering delivery area A is funneled so that a given amount passes over progressively less surface during transit. This reduces the opportunities for deposition and also increases the energy of the transporting agent, thus resulting in increased sediment delivery efficiency. At the other extreme, delivery area C spreads material and water over progressively more area thus reducing the transporting energy and increasing opportunities for in-transit deposition. Delivery area B represents an intermediate situation between A and C. A relative comparison of the three areas would have A delivering more sediment than B, which delivers more than C.

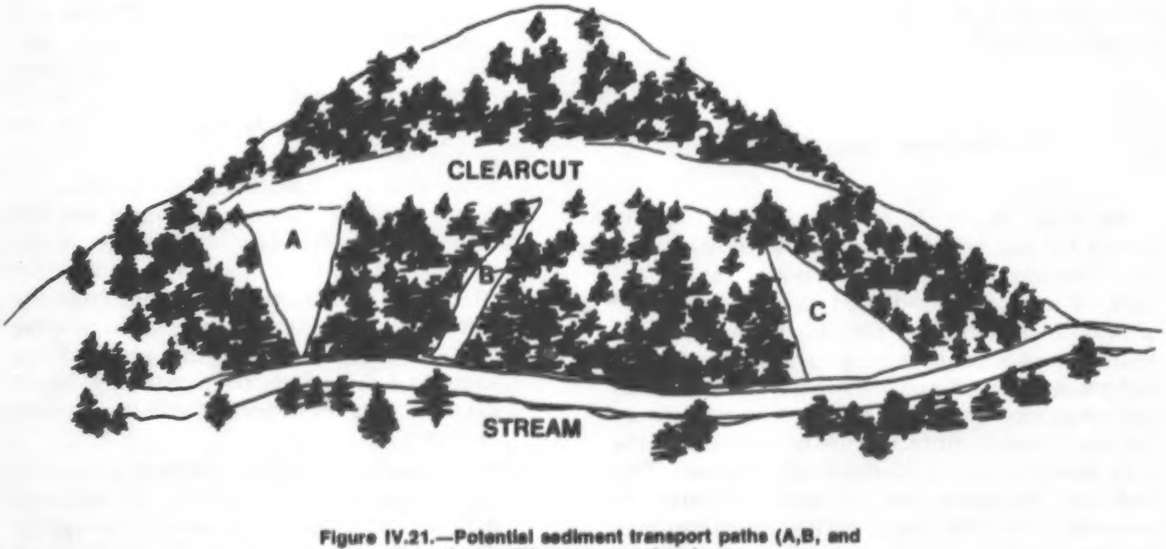


Figure IV.21.—Potential sediment transport paths (A,B, and C) for different parts of a slope.

Any working sediment delivery model must have clearly defined factors which represent the amount of surface runoff available for transporting sediment, the length of the transport path, the gradient of the path, the shape and changes in surface area of the path, a measure of surface microrelief, and a measure of ground cover. All of these factors should have measurable parameters and be combined together with the proper coefficients. To date, there is no accurate way to estimate the amount of surface runoff that might be available for sediment delivery in the forest environment, the actual shape and location of sediment delivery paths, degree of surface roughness, or characteristics of slope shape. An understanding of how to combine these factors or what coefficients to use is not known for most situations.

PROCEDURAL CONCEPTS: ESTIMATING SEDIMENT DELIVERY

This section discusses the concepts necessary for estimating sediment delivery and for evaluating the individual parameters involved. It is organized according to a conceptual perception of sediment delivery and corresponds with the flow chart of figure IV.1. An outline of the overall procedure for estimating sediment delivery to a stream from surface erosion sources is presented in "The Procedure" section of this chapter. A detailed example for using the procedure is provided in "Chapter VIII: Procedural Examples." All concepts discussed here are necessary for using the overall procedure.

The Sediment Delivery Index

An index approach is recommended to help bridge the gap between the need to estimate how much sediment reaches a stream channel and the lack of a working sediment delivery model to provide such estimates. This approach provides a relative evaluation of seven generally accepted environmental factors and one site specific factor that are considered important in the sediment delivery process. These eight factors are not necessarily the only ones that may be needed in all situations. This indexing procedure has not been validated by research. Therefore, the computed quantities may be different from measured quantities of sediment delivered to a stream channel. Use of the index is only an aid in evaluating the relative effects of different management practices on sediment delivery from a given forest area.

Evaluation Factors

For this discussion, each of the following eight factors is considered as though it acts independently of any other factor. In reality, these factors interact with each other in complex ways.

1. **Transport agent (e.g., water availability).** — Surface runoff from rainfall and snowmelt is an important factor in the movement of eroded material. It is estimated that overland flow rates from sheet and rill erosion rarely exceed 1 cfs on agricultural land and generally are less than 0.1 cfs on forest lands in the United States.
2. **Texture of eroded material.** — Assuming that aggregates do not form, individual particles of fine-textured soil material require less energy for delivery than particles of coarse-textured material. Sediment delivery efficiencies are higher on an area dominated by fine-textured material than on an area dominated by coarse-textured materials if the other factors influencing sediment delivery are equal.
3. **Ground cover.** — Ground cover (forest floor litter, vegetation, and rocks) creates a tortuous pathway for eroded particles to travel which allows time for the eroded material to settle from surface runoff water (Tollner and others 1976). Protective ground cover may also prevent raindrop impact energy from creating increased flow turbulance which would increase the carrying capacity of the runoff flow.
4. **Slope shape.** — Concave slopes between the source area and the stream channel promote deposition of the larger size fraction of the transported material (Neibling and Foster 1977). Convex slopes create more favorable conditions for increasing the material carrying capacity of the transporting agent. Slope shape is a difficult factor to quantify, but it seems to play an important role in sediment delivery.
5. **Slope gradient.** — Slope gradient, along with the volume of water available for sediment delivery, provides the necessary energy to deliver the eroded material. The efficiency of

the sediment delivery process increases with increasing slope gradient.

6. **Delivery distance.** — Increasing the distance from a sediment source to a stream channel or diversion ditch increases the effect that other factors have on the amount of sediment actually delivered. On the other hand, if a sediment source is very close to a stream channel, the other factors affecting sediment delivery have proportionally less opportunity to reduce the amount of sediment delivered.
7. **Surface roughness.** — Roughness of the soil surface affects sediment delivery similarly to that of ground cover. Rougher surfaces create more tortuous pathways for eroded particles to pass over and more surface area for water infiltration than smooth surfaces for a given area (Meeuwig 1970).
8. **Site specific factors.** — In many parts of the United States, unique forest environments and/or soil factors influence the sediment delivery efficiency. For example, soil nonwettability (DeBano and Rice 1975), mineralogy such as the Idaho batholith described by Megahan (1974), biological activity, or fire can change the sediment delivery efficiency of some forest lands. Within forested areas of the southeast United States, microrelief adjacent to stream channels may cause concentrated water flows, thus having a large effect on sediment delivery efficiency. Some soils have a greater tendency than others to form stable aggregates, hence reducing the sediment delivery efficiency.

Determining The Sediment Delivery Index

The stiff diagram shown in figure IV.22 uses vectors to display the magnitude and scale of each major factor identified as influencing sediment delivery. The area of the polygon created by connecting the observed, anticipated, or measured value for each factor is determined and related to the total possible area (the polygon formed by connecting the outer limits of each vector) of the graph. The percentage of area inside the polygon is coupled to the delivery index through the use of skewed probit transformations (Bliss 1935). Small polygonal areas surrounding the midpoint indicate a low probability of efficient sediment delivery, or, in other words, a very low sediment delivery index. Sediment delivery indexes will be low in most forest ecosystems managed by the best forest practices. Polygons approaching the outer limits of the stiff diagram indica[illegible] high probability of efficient sediment delivery. The fraction of the total stiff diagram area formed by a given polygon is adjusted using figure IV.23, to give the sediment delivery index.

The scale and magnitude of the vectors in figure IV.22 have been defined as follows:

1. The magnitude of the transport agent is determined by the equation:

$$F = CRL \qquad (IV.12)$$

where:

F = water availability,

C = $2.31 \times 10^{-5} \frac{ft^2\ hr}{in\ sec}$ (a conversion constant)

R = maximum anticipated precipitation and/or snowmelt rate minus infiltration in units of in/hr from local records, and

L = slope length in feet of the sediment source area (perpendicular to contours).

Values of F for given values of R and L are in table IV.8.

The maximum scale value in figure IV.22 is 0.1 cfs. If the flow is calculated to exceed 0.1 cfs, use the scale factor of 0.1 for water availability. This model assumes that the precipitation input exceeds the site infiltration capacity causing overland flow conditions at the lower boundary of the eroded material source area. If no water is available then the sediment delivery index is zero (0.0).

2. Texture of eroded material is expressed as percent of eroded material that is finer than 0.05 mm (silt size). A particle diameter less than 0.05 mm was shown to be highly transportable for sediment movement (Neibling and Foster 1977). A scale factor of zero indicates that the eroded material contains no material less than 0.05 mm diameter, and a factor of 100 percent indicates that all of the eroded material is 0.05 mm or less in diameter.
3. Ground cover that is in actual contact with the soil surface, is expressed in percent cover between 0 (bare soil surface) and 100 (mineral soil surface completely covered). This factor is scaled based on unpublished data by Dissmeyer[2] which relates relative ground cover

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[2] Personal communication of unpublished material from G. Dissmeyer, USDA Forest Service, State and Private Forestry, Atlanta, Ga.

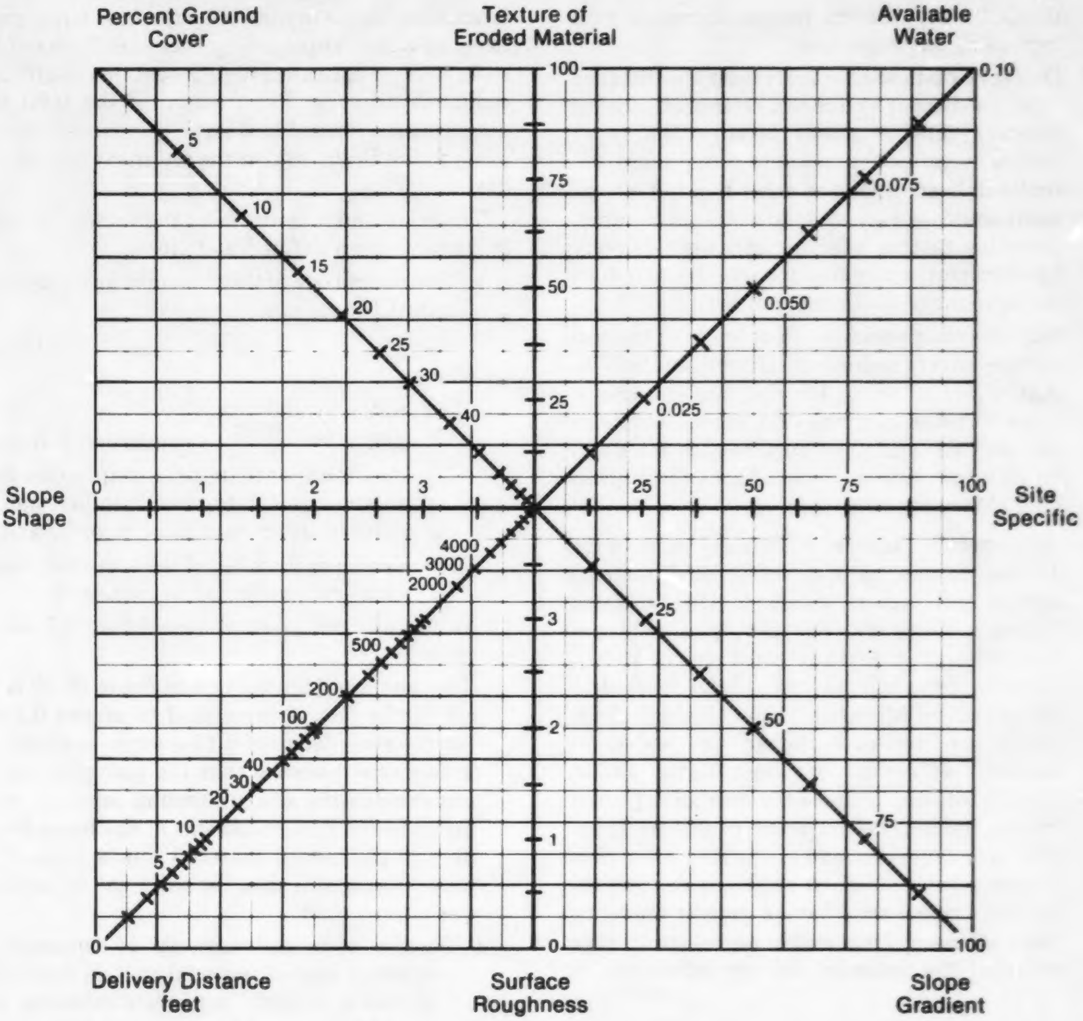

Figure IV.22—Stiff diagram for estimating sediment delivery.

density influence to overland water flow.

4. Slope shape is scaled in magnitude between 0 and 4, with 4 being a slope that is convex from the boundary of the source area to the stream channel. A scale factor of 0 describes a slope concave from the boundary of the source area to the stream channel, while a factor of 2 shows that one-half of the slope is concave and the other half is convex or that the entire slope is uniformly straight. A factor of 3 indicates that a larger percentage of the slope is convex in shape.
5. The slope gradient is the vertical elevation difference between the lower boundary of the source area and the stream channel divided by the horizontal distance and expressed as a percent between 0 and 100.
6. The distance factor is the $\log_{10}$ of the distance in feet from the boundary of the source area to a stream channel or ditch. Distances greater than 10,000 feet (3,050 m) are considered infinite. The distance vector is marked using a $\log_{10}$ scale so that distances are entered directly onto the vector in figure IV.22.

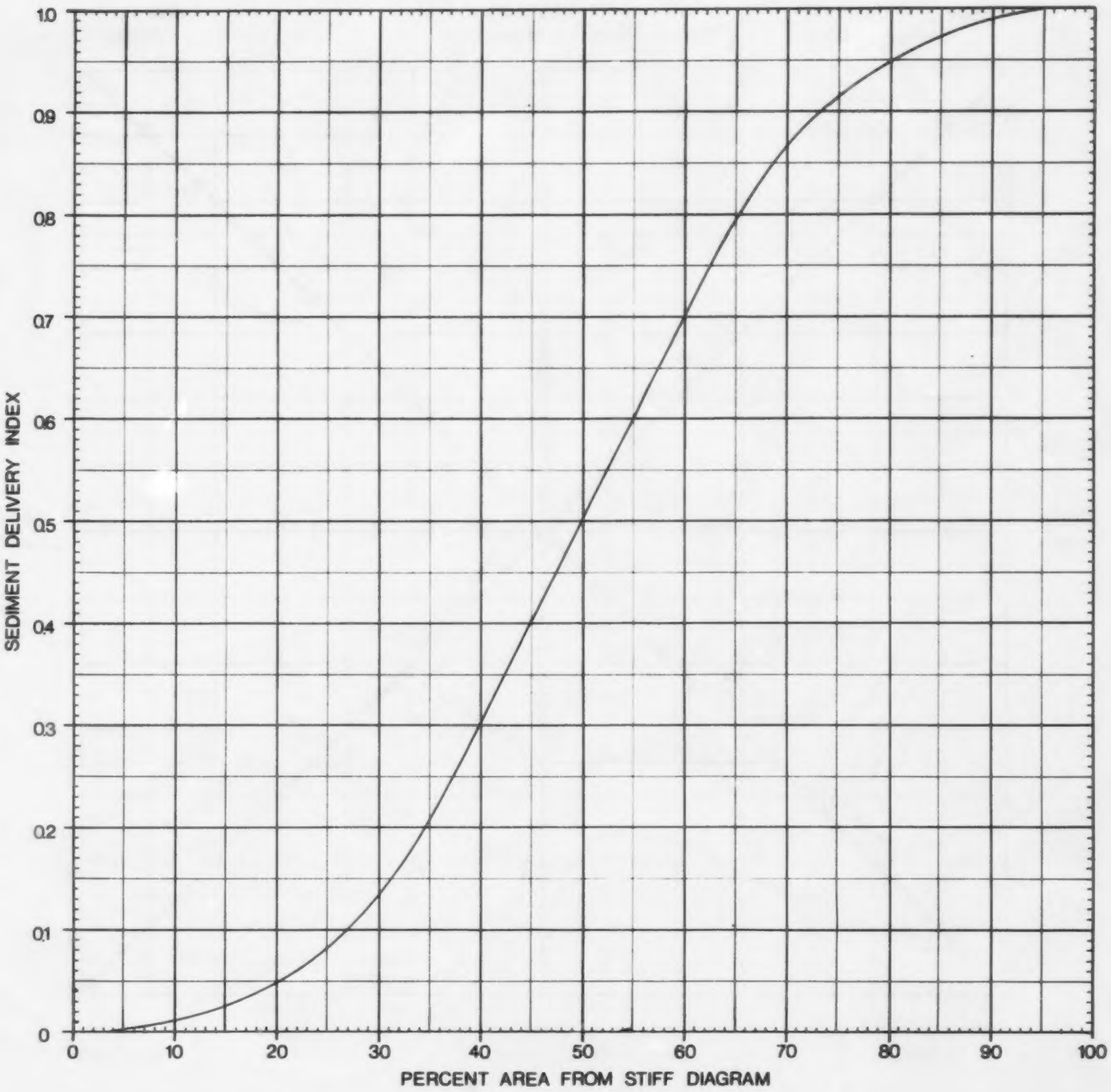

Figure IV.23.—Relationship between polygon area on stiff diagram and sediment delivery index.

7. The roughness factor is scaled in magnitude between 0 and 4 with 0 being an extremely smooth forest floor surface condition and 4 being a very rough surface. This is a subjective evaluation of soil surface conditions.

8. The site specific factor influencing delivery ratios is scaled between 0 and 100 and must be **assigned** its effective magnitude by a user familiar with the unique condition of the site.

Appropriate factor values are plotted on each vector of the graphic sediment delivery model (fig. IV.24). Lines are drawn to connect all plotted points to form an enclosed, irregular polygon. If a site specific factor is not used, draw a line directly between plotted points on the slope gradient and available water vectors. Determine the area inside the polygon by: measuring with a planimeter, estimating with a dot grid, or calculating and summing the areas of the individual triangles. Determine the percent of the total graph area that is

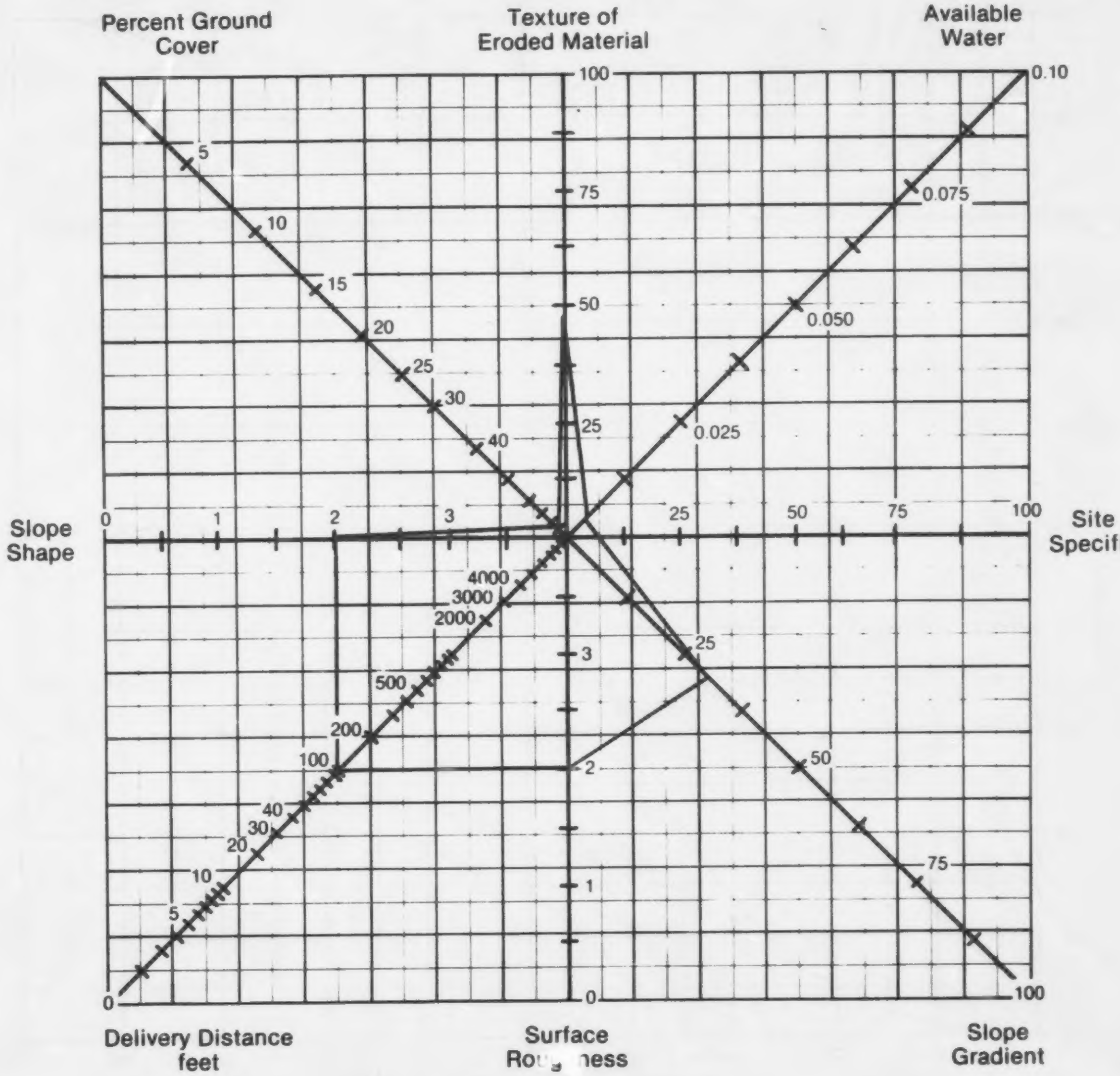

Figure IV.24.—Example of graphic sediment delivery model for road R3.1.

within the polygon. Using the S-shaped probit curve in figure IV.23, determine the sediment delivery index by using the percent area of the polygon from figure IV.24.

Table IV.8.—Water availability values for given source area slope length (ft) and runoff (in/hr)[1]

Surface slope length	Runoff															
	.025	.05	0.75	1.0	1.25	1.5	1.75	2.0	2.25	2.5	2.75	3.0	3.25	3.5	3.75	4.0
10	.00006	.00012	.00017	.00023	.00029	.00035	.00040	.00046	.00052	.00058	.00064	.00069	.00075	.00081	.00087	.00092
20	.00012	.00023	.00035	.00046	.00058	.00069	.00081	.00092	.0010	.0012	.0013	.0014	.0015	.0016	.0017	.0018
30	.00017	.00035	.00052	.00069	.00087	.0010	.0012	.0014	.0016	.0017	.0019	.0021	.0023	.0024	.0026	.0028
40	.00023	.00046	.00069	.00092	.0012	.0014	.0016	.0018	.0021	.0023	.0025	.0028	.0030	.0032	.0035	.0037
50	.00029	.00058	.00087	.0012	.0014	.0017	.0020	.0023	.0026	.0029	.0032	.0035	.0038	.0040	.0043	.0046
75	.00043	.00087	.0013	.0017	.0022	.0026	.0030	.0035	.0039	.0043	.0048	.0052	.0056	.0061	.0065	.0069
100	.00058	.0012	.0017	.0023	.0029	.0035	.0040	.0046	.0052	.0058	.0064	.0069	.0075	.0081	.0087	.0092
150	.00087	.0017	.0026	.0035	.0043	.0052	.0061	.0069	.0078	.0087	.0095	.010	.011	.012	.013	.014
200	.0012	.0023	.0035	.0046	.0058	.0069	.0081	.0092	.010	.012	.013	.014	.015	.016	.017	.018
250	.0014	.0029	.0043	.0058	.0072	.0087	.010	.012	.013	.014	.016	.017	.019	.020	.022	.023
300	.0017	.0035	.0052	.0069	.0087	.010	.012	.014	.016	.017	.019	.021	.023	.024	.026	.028
350	.0020	.0040	.0061	.0081	.010	.012	.014	.016	.018	.020	.022	.024	.026	.028	.030	.032
400	.0023	.0046	.0069	.0092	.012	.014	.016	.018	.021	.023	.025	.028	.030	.032	.035	.037
450	.0026	.0052	.0078	.010	.013	.016	.018	.021	.023	.026	.029	.031	.034	.036	.039	.042
500	.0029	.0058	.0087	.012	.014	.017	.020	.023	.026	.029	.032	.035	.038	.040	.043	.046
1000	.0058	.012	.017	.023	.029	.035	.040	.046	.052	.058	.064	.069	.075	.081	.087	.092

[1] The table values were obtained by the formula:

$$F = \left(2.31 \times 10^{-5}\ \frac{\text{ft}^2\,\text{hr}}{\text{in sec}}\right)\left(\text{Runoff in/hr}\right)\left(\text{slope length ft.}\right)$$

Estimating Sediment Delivery By Activity

Each land-disturbing activity should have an estimate of soil loss for the location where it occurs and a delivery index based on site characteristics. An estimate of the amount of sediment which might reach a stream channel can be obtained by multiplying the surface soil loss (tons/year) by the sediment delivery index for each erosion response unit.

All of the procedures used to arrive at an estimate of surface soil loss and sediment delivered to a stream channel only provide a way to evaluate alternative management practices. Only on-the-ground monitoring can verify if the objectives have been met by the management strategy.

CONSIDERATIONS FOR REDUCING SEDIMENT DELIVERY

Theoretically it is possible to reduce sediment delivered to a stream channel by making appropriate changes in any of the index factors. In actual practice, some factors are easier to change than others. The following tabulation describes the basic concepts underlying each factor and the changes brought about by controls for sediment delivery. This conceptual presentation is to aid understanding of controls and determining which control practice to use. Details of specific control practices may be found in "Chapter II: Control Opportunities."

Sediment delivery factors	Preventive	Mitigative
Water availability	Control over the rainfall rate is not likely to occur because it is a function of overall weather patterns.	
	Use management practices that maintain high infiltration rates. Avoid such things as soil compaction which changes soil structure and permeability. Control of soil moisture content by high consumptive use promotes infiltration.	Increase infiltration rates by breaking surface crusts, and incorporating organic matter or other soil amendments to improve aggregation of soil particles. Promote vegetative growth for high consumptive water use and desirable soil structure development.
	Where snowmelt is influential, use management practices which will not create significant increases in the amount of solar energy reaching the snow pack.	Reduce snowmelt runoff rates by increasing the interception of solar energy above the snow surface.
Texture of eroded material	Soil texture is controlled by soil-forming factors that are generally related to mineralogy and weathering.	
	Maintain natural, stable soil aggregates which will act as a coarse-textured material in response to sediment delivery forces.	Use soil amendments which promote floculation and development of aggregates.

Sediment delivery factors	Preventive	Mitigative
Ground cover	Control and design forest management activities to minimize forest floor disturbance.	Add mulch, establish vegetation, distribute residues, or use other practices to create long tortuous pathways for water flow and sediment delivery.
Slope shape	Control location and design of various types of construction and other activities that would create adverse slope shapes.	Design concave slope segments for sediment delivery control on construction sites or with other activities.
Slope gradient	Control location and design of various types of construction activities to minimize the creation of steep slopes.	Reduce slope gradients created by construction and other activities wherever possible.
Delivery distance	Locate activities well away from stream channels to maintain long delivery paths.	Relocate activity sites to increase overall delivery distance to a stream channel.
Surface roughness	Design activities to maintain natural surface roughness. Avoid creating channels that shortcut natural tortuous pathways.	Create ridges and depressions on the surface to trap sediment and increase water infiltration.
Site specific factors	This will depend upon the characteristics of the chosen site factor.	

APPLICATIONS, LIMITATIONS AND PRECAUTIONS: SEDIMENT DELIVERY

Very few attempts have been made to verify the reliability of sediment delivery models due to the difficulty of obtaining sufficient data for testing. The following limitations attributed to this model are not based on actual data but are deduced as being important. Future research may add to or change ideas about these limitations.

1. Only sheet flow surface runoff is addressed with the sediment delivery index. If channeled flow develops, other approaches must be used to describe sediment delivery.
2. The choice of factors used to describe sediment delivery is thought to apply in all cases; however, these may vary with future research.
3. The scaling of each factor on the stiff diagram is based on the best available information; however, new research information will probably show a need for some changes.
4. Many factors work together in various ways to influence sediment delivery. These interactions have not been studied extensively and may not be expressed correctly by the model.
5. The model assumes that the only water used to move the sediment is generated on the sediment delivery path. It does not consider the potential for additional water from other sources on the slope. Solution of this problem depends on the development of a satisfactory water routing model.
6. Individual sediment delivery routes have various shapes and overall surface areas which are not accounted for by the model.
7. Infiltration rates may be different on disturbed areas than in sediment filter strips. Only the infiltration rate for the disturbed site is used.
8. Antecedent soil moisture conditions are not incorporated into the model. If sediment delivery is most likely to occur during certain time periods with particular soil moisture characteristics, then some adjustments could be made in the infiltration rate.

THE PROCEDURE

ESTIMATING SEDIMENT DELIVERY FROM SURFACE EROSION SOURCES

The following steps outline the overall procedure for estimating sediment delivery to a stream from surface erosion sources. Steps 1 through 11 represent the procedure for estimating surface soil loss, and steps 12 through 15 represent the procedure for estimating sediment delivery. A complete example for using the procedure is provided in "Chapter VIII: Procedural Examples." Most of the steps are self explanatory; however, the specific concepts, parameters and computations involved in the procedure were discussed earlier in this chapter under "Procedural Concepts: Estimating Soil Surface Loss" and "Procedural Concepts: Estimating Sediment Delivery."

Step 1. — Identify the watershed of interest and obtain the necessary materials and information.

Step 2. — Delineate the drainage network in as much detail as the topographic base will allow.

Step 3. — Delineate the hydrographic divides relative to the drainage network identified in Step 2 above.

Step 4. — Delineate soil and vegetative ground cover units based on appropriate data.

Step 5. — Show the proposed land use activity in detail, delineating cutting units, roads, landings and skid trails, etc.

Step 6. — Using overlays, incorporate all map-related information onto a single map base.

Step 7. -- Show the direction of water flow for each hydrographic source area.

Step 8. — Set up worksheets for estimating potential sediment load (wkshts. IV.1—IV.8).

Step 9. — List each source area that is delineated, and number by erosion response unit.

Step 10. —Working in individual hydrographic areas, determine for each erosion response unit the values for the variables R, K, LS, and VM.

Step 11. — Using the values from step 10, calculate the estimated surface soil loss (tons/year).

Step 12. — Working by erosion response units, determine for each treatment source the sediment delivery index (SD_I).

Step 13. — Calculate the estimated tons per year of sediment input to the stream system by each erosion response unit.

Step 14. — Arrange erosion response unit sediment values in matrix by treatment type.

Step 15. — Evaluate results.

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APPENDIX IV.A.:

GULLY EROSION

A gully is a channel created by concentrated but intermittent flow of water, usually during and immediately following heavy rains; however, concentration of snowmelt runoff may also be a factor. Gullies are deep enough to interfere with, and usually are not obliterated by, normal tillage or silvicultural activities.

Quantitative estimates of soil loss and sediment produced by gully erosion must be based on professional judgment about the overall erosional processes in a particular location. Changes in the geometry of a gully can provide an estimate of the amount of material being eroded. Rates of headward cutting, final average width, and depth of each cycle of cutting can be used to compute the volume of soil material removed from the gully. The mass of soil material is calculated by multiplying the volume by an appropriate bulk density factor for the particular soil.

Bulk density is usually expressed in grams per cubic centimeter or pounds per cubic foot. Conversion factors are:

$$\text{g/cm}^3 = (0.016)\ (\text{lb/ft}^3)$$
$$\text{lb/ft}^3 = (62.43)\ (\text{g/cm}^3)$$

An estimate of the proportion of eroded material actually delivered to a stream channel may be needed if the gully does not connect directly to a stream system.

APPENDIX IV.B.:

EROSION OVER TIME

To predict long-term, onsite soil losses, changes in the various parameters in the soil loss equation must be estimated and redefined for each year. The most important is the VM factor. The K factor needs to be changed if management causes long-term changes in soil characteristics to occur. Future changes in VM and K factors become, at best, an educated guess about what might happen in any given year. Time trend analysis should be based on both best condition and worst condition parameters in order to show a range of possible outcomes.

The part of the equation which is most likely to change with time is the VM factor. The effects of roughness and vegetation change with time either as the surface roughness is broken down or as the vegetation becomes healthier and covers more of the surface. Estimates of VM changes must be made relative to the time period of interest.

Fine materials in the surface soil tend to erode away, leaving the heavier material, which is less erosive to protect the surface (Clyde and others 1976, Megahan 1974, Wischmeier and Mannering 1969). Other long-term changes due to management must also be evaluated.

APPENDIX IV.C.:
CONTROLLING DITCH EROSION

The simulation procedures in Chapter IV, "Surface Erosion" do not consider road ditch erosion. There is no technique to estimate the amount of sediment delivered to the stream from road ditches. Because some controls are designed to affect road ditch erosion, the Manning formula (U.S. Army Engineering School 1973) is used to estimate the effect of various controls on road ditch stability and water velocity. Manning's formula is:

$$V = \left(\frac{1.49}{n}\right)\left(R^{0.66}\right)\left(S^{0.5}\right) \qquad \text{(IV.C.1)}$$

where:

V = velocity of flow in ft/sec,

R = hydraulic radius, = $\dfrac{\text{cross-section area of the channel}}{\text{wetted perimeter (ft)}}$

(from tables IV.C.2 through IV.C.5)

S = slope of the channel in ft/ft, and

n = friction factor which depends on the material comprising the channel from Table IV.C.1

Manning formula limitations: (1) It will not predict amounts of sediment delivered to the stream from a road ditch. (2) The formula is based on the amount of energy necessary to move particles of given size, and does not account for detachment. Soils with strong structure are likely to be more resistant than soils with weak structure. (3) The maximum recommended velocity figures are based on energy/particle size relationships.

An Example For Use Of The Manning Formula

Problem — Determine whether the water velocity for a given road ditch will be below critical levels for erosion. If velocities are too high, make and evaluate changes.

Solution

1. Obtain hydraulic radius for channel. Assume that the road ditch is a symmetrical, triangular channel 1.3 feet deep with 2½:1 slopes. Check table IV.C.2 for hydraulic radius which is 0.60 feet for this size channel.
2. Obtain slope of channel. (Slope of the road ditch is measured and found to be 0.003 feet per feet.)
3. Obtain roughness coefficient from table IV.C.1.(The channel sides, in this case, are sand and have a friction factor (n) of 0.020.)
4. Obtain maximum allowable velocity. (For a sandy channel, the maximum velocity is 1-2 feet per second (table IV.C.1).)
5. Obtain V (velocity) for the specified channel by using the nomograph (fig. IV.C.1). (Velocity for the specified ditch is 2.9 feet per second.)
6. Compare the predicted velocity for the specified ditch with the maximum recommended velocity for sandy channels.

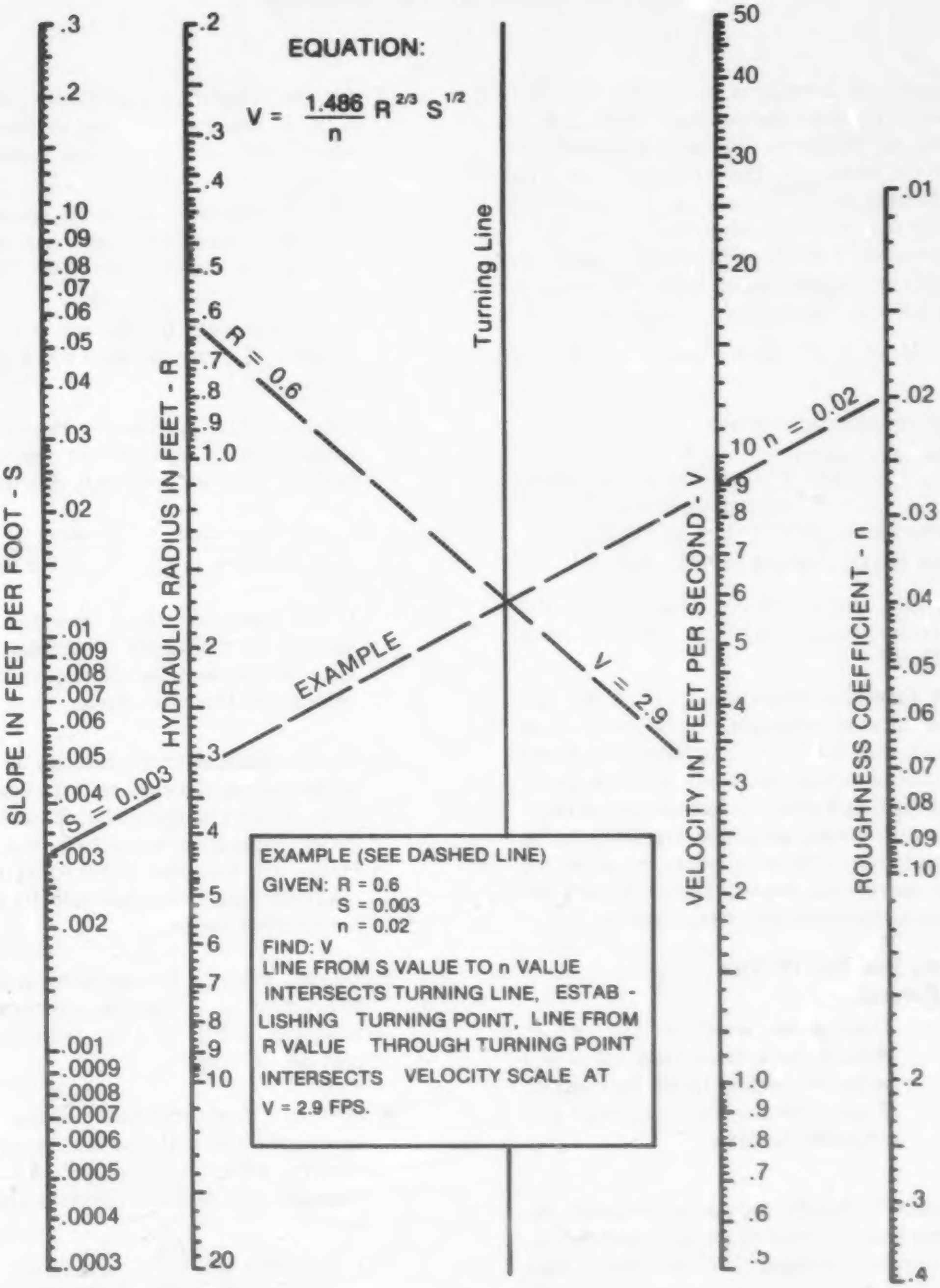
specified ditch	maximum velocity
2.9 ft/sec	1-2 ft/sec

If the specified ditch has too great a velocity, it will erode. Therefore, controls must be chosen that will reduce the water velocity in the road ditch.

7. Water velocities in ditches can be reduced by protecting the channel with vegetation, rock, or by changing the channel shape. (With vegetative protection, the friction factor (n) becomes 0.030-0.050 and the maximum recommended velocity becomes 3-4 feet per second.)
8. Obtain velocity for specified ditch with vegetative protection by referring to the nomograph (fig. IV.C.1). Velocity is 1.9 feet per second.
9. Compare the predicted velocity for the specified ditch with the maximum recommended velocity for vegetation protected channels (average turf) with easily eroded soil.

specified ditch	maximum velocity
1.9 ft/sec	3-4 ft/sec

10. If the specified ditch has a lower velocity than the recommended maximum velocities, it should be stable as long as the vegetation remains intact.



EQUATION:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

EXAMPLE (SEE DASHED LINE)

GIVEN: R = 0.6
S = 0.003
n = 0.02

FIND: V

LINE FROM S VALUE TO n VALUE INTERSECTS TURNING LINE, ESTABLISHING TURNING POINT, LINE FROM R VALUE THROUGH TURNING POINT INTERSECTS VELOCITY SCALE AT V = 2.9 FPS.

Figure IV.C.1 Nomograph for Manning formula.

Table IV.C.1—Values for Manning's n and maximum permissible velocity of flow in open channels

Ditch lining	Manning's n	V_{max} fps[1]
1. Natural earth		
a. Without vegetation		
(1) Rock		
(a) Smooth and uniform	0.035 - 0.040	20
(b) Jagged & irregular	0.040 - 0.045	15 - 18
(2) Soils		

			Unified	USDA			
Coarse grained	Gravel and gravelly soils		GW	Gravel		0.022 - 0.024	6 - 7
			GP	Gravel		C.023 - 0.026	7 - 8
			GM	Loamy Gravel	d	0.023 - 0.025	3 - 5
					u	0.022 - 0.020	2 - 4
			GC	Gravelly Loam Gravelly Clay		0.024 - 0.026	5 - 7
	Sand and sandy soils		SW	Sand		0.020 - 0.024	1 - 2
			SP	Sand		0.022 - 0.024	1 - 2
			SM	Loamy Sand	d	0.020 - 0.023	2 - 3
					u	0.021 - 0.023	2 - 3
			SC	Sandy Loam		0.023 - 0.025	3 - 4
Fine grained	Silts and clays	LL 50	CL	Clay Loam Sandy Clay Loam Silty Clay		0.022 - 0.024	2 - 3
			ML	Silt Loam Very Fine Sand Silt		0.023 - 0.024	3 - 4
		LL 50	OL	Mucky Loam		0.022 - 0.024	2 - 3
			CH	Clay		0.022 - 0.023	2 - 3
			MH	Silty Clay		0.023 - 0.024	3 - 5
			OH	Mucky Clay		0.022 - 0.024	2 - 3
Highly Organic			PT	Peat		0.022 - 0.025	2 - 3

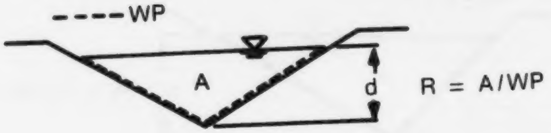
[1] Maximum recommended velocities

Table IV.C.1—Continued

Ditch lining	Manning's n	V_{max} fps[1]
b. With vegetation		
(1) Average turf		
(a) Erosion resistant soil	0.050 - 0.070	4 - 5
(b) Easily eroded soil	0.030 - 0.050	3 - 4
(2) Dense turf		
(a) Erosion resistant soil	0.070 - 0.090	6 - 8
(b) Easily eroded soil	0.040 - 0.050	5 - 6
(3) Clean bottom with bushes on sides	0.050 - 0.080	4 - 5
(4) Channel with tree stumps		
(a) No sprouts	0.040 - 0.050	5 - 7
(b) With sprouts	0.060 - 0.080	6 - 8
(5) Dense weeds	0.080 - 0.120	5 - 6
(6) Dense brush	0.100 - 0.140	4 - 5
(7) Dense willows	0.150 - 0.200	8 - 9
2. Paved	(Construction)	
a. Concrete, w/all surfaces:	**Good** **Poor**	
(1) Trowel finish	0.012 - 0.014	20
(2) Float finish	0.013 - 0.015	20
(3) Formed, no finish	0.014 - 0.016	20
b. Concrete bottom, float finished, w/sides of:		
(1) Dressed stone in mortar	0.015 - 0.017	18 - 20
(2) Random stone in mortar	0.017 - 0.020	17 - 19
(3) Dressed stone or smooth concrete rubble (riprap)	0.020 - 0.025	15
(4) Rubble or random stone (riprap)	0.025 - 0.030	15
c. Gravel bottom, sides of:		
(1) Formed concrete	0.017 - 0.020	10
(2) Random stone in mortar	0.020 - 0.023	8 - 10
(3) Random stone or rubble (riprap)	0.023 - 0.033	8 - 10
d. Brick	0.014 - 0.017	10
e. Asphalt	0.013 - 0.016	18 - 20

[1] Maximum recommended velocities

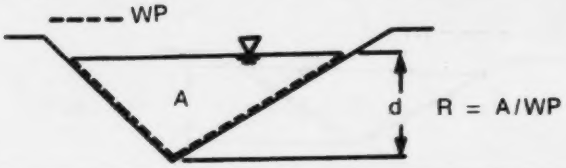
Table IV.C.2. Hydraulic radius (R) and area (A) of symmetrical triangular channels.



Depth, d (feet)	Slope ratio 1:1		1½:1		2:1		2½:1		3:1		4:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	0.25	0.18	0.38	0.21	0.50	0.22	0.63	0.23	0.75	0.24	1.00	0.24
0.6	0.36	0.21	0.54	0.25	0.72	0.27	0.90	0.28	1.08	0.28	1.44	0.29
0.7	0.49	0.25	0.74	0.29	0.98	0.31	1.23	0.32	1.47	0.33	1.96	0.34
0.8	0.64	0.28	0.96	0.33	1.28	0.36	1.60	0.37	1.92	0.38	2.56	0.39
0.9	0.81	0.32	1.21	0.37	1.62	0.40	2.03	0.42	2.43	0.43	3.24	0.44
1.0	1.00	0.35	1.50	0.42	2.00	0.45	2.50	0.46	3.00	0.47	4.00	0.49
1.1	1.21	0.39	1.82	0.46	2.42	0.49	3.03	0.51	3.63	0.52	4.84	0.53
1.2	1.44	0.42	2.16	0.50	2.88	0.54	3.60	0.56	4.32	0.57	5.76	0.58
1.3	1.69	0.46	2.54	0.54	3.38	0.58	4.23	0.60	5.07	0.62	6.76	0.63
1.4	1.96	0.50	2.94	0.58	3.92	0.63	4.90	0.65	5.88	0.66	7.84	0.68
1.5	2.25	0.53	3.38	0.62	4.50	0.67	5.63	0.70	6.75	0.71	9.00	0.73
1.6	2.56	0.57	3.84	0.67	5.12	0.72	6.40	0.74	7.68	0.76	10.24	0.78
1.7	2.89	0.60	4.34	0.71	5.78	0.76	7.23	0.79	8.67	0.80	11.56	0.83
1.8	3.24	0.64	4.86	0.75	6.48	0.80	8.10	0.84	9.72	0.85	12.96	0.87
1.9	3.61	0.67	5.42	0.79	7.22	0.85	9.03	0.88	10.83	0.90	14.44	0.92
2.0	4.00	0.71	6.00	0.83	8.00	0.90	10.00	0.93	12.00	0.95	16.00	0.97
2.5	6.25	0.88	9.38	1.04	12.50	1.12	15.63	1.16	18.75	1.19	25.00	1.21
3.0	9.00	1.06	13.50	1.25	18.00	1.34	22.50	1.39	27.00	1.42	36.00	1.46
3.5	12.25	1.24	18.38	1.45	24.50	1.56	30.62	1.62	36.75	1.66	49.00	1.70
4.0	16.00	1.41	24.00	1.66	32.00	1.78	40.00	1.85	48.00	1.90	64.00	1.94

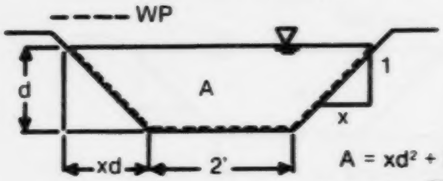
	5:1		6:1		7:1		8:1		9:1		10:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	1.25	0.25	1.50	0.25	1.75	0.25	2.00	0.25	2.25	0.25	2.50	0.25
0.6	1.80	0.29	2.16	0.30	2.52	0.30	2.88	0.30	3.24	0.30	3.60	0.30
0.7	2.45	0.34	2.94	0.35	3.43	0.35	3.92	0.35	4.41	0.35	4.90	0.35
0.8	3.20	0.39	3.84	0.39	4.48	0.40	5.12	0.40	5.76	0.40	6.40	0.40
0.9	4.05	0.44	4.86	0.44	5.67	0.45	6.48	0.45	7.29	0.45	8.10	0.45
1.0	5.00	0.49	6.00	0.49	7.00	0.49	8.00	0.50	9.00	0.50	10.00	0.50
1.1	6.05	0.54	7.26	0.54	8.47	0.55	9.68	0.55	10.89	0.55	12.10	0.55
1.2	7.20	0.59	8.64	0.59	10.08	0.59	11.52	0.60	12.96	0.60	14.40	0.60
1.3	8.45	0.64	10.14	0.64	11.83	0.64	13.52	0.64	15.21	0.65	16.90	0.65
1.4	9.80	0.69	11.76	0.69	13.72	0.69	15.68	0.69	17.64	0.70	19.60	0.70
1.5	11.25	0.74	13.50	0.74	15.75	0.74	18.00	0.74	20.25	0.75	22.50	0.75
1.6	12.80	0.78	15.36	0.79	17.92	0.79	20.48	0.79	23.04	0.80	25.60	0.80
1.7	14.45	0.83	17.34	0.84	20.23	0.84	23.12	0.84	26.01	0.84	28.90	0.85
1.8	16.20	0.88	19.44	0.89	22.68	0.89	25.92	0.89	29.16	0.89	32.40	0.90
1.9	18.05	0.93	21.66	0.94	25.27	0.94	28.88	0.94	32.49	0.94	36.10	0.95
2.0	20.00	0.98	24.00	0.99	28.00	0.99	32.00	0.99	36.00	0.99	40.00	1.00
2.5	31.25	1.23	37.50	1.23	43.75	1.24	50.00	1.24	56.25	1.24	62.50	1.24
3.0	45.00	1.47	54.00	1.48	63.00	1.48	72.00	1.49	81.00	1.49	90.00	1.49
3.5	61.25	1.72	73.50	1.72	85.75	1.73	98.00	1.74	110.25	1.74	122.50	1.74
4.0	80.00	1.96	96.00	1.97	112.00	1.98	128.00	1.98	144.00	1.98	160.00	1.99

Table IV.C.3. Hydraulic radius (R) and area (A) of nonsymmetrical triangular channels.



Depth, d (feet)	Slope ratio											
	1:1 - 3:1		1½:1 - 3:1		2:1 - 3:1		2½:1 - 3:1		4:1 - 3:1		5:1 - 3:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	0.50	0.22	0.56	0.23	0.63	0.23	0.69	0.23	0.88	0.24	1.00	0.24
0.6	0.72	0.26	0.81	0.27	0.90	0.28	0.99	0.28	1.26	0.29	1.44	0.29
0.7	0.98	0.31	1.10	0.32	1.23	0.32	1.35	0.33	1.72	0.34	1.96	0.34
0.8	1.28	0.35	1.44	0.36	1.60	0.37	1.76	0.38	2.24	0.38	2.56	0.39
0.9	1.62	0.39	1.82	0.41	2.03	0.42	2.23	0.42	2.84	0.43	3.24	0.44
1.0	2.00	0.44	2.25	0.45	2.50	0.46	2.75	0.47	3.50	0.48	4.00	0.48
1.1	2.42	0.48	2.72	0.50	3.03	0.51	3.33	0.52	4.24	0.53	4.84	0.53
1.2	2.88	0.52	3.24	0.54	3.60	0.56	3.96	0.56	5.04	0.58	5.76	0.58
1.3	3.38	0.57	3.80	0.59	4.23	0.60	4.65	0.61	5.92	0.63	6.76	0.63
1.4	3.92	0.61	4.41	0.63	4.90	0.65	5.39	0.66	6.86	0.67	7.84	0.68
1.5	4.50	0.66	5.06	0.68	5.63	0.69	6.19	0.70	7.88	0.72	9.00	0.73
1.6	5.12	0.70	5.76	0.73	6.40	0.74	7.04	0.75	8.96	0.77	10.24	0.77
1.7	5.78	0.74	6.50	0.77	7.23	0.79	7.95	0.80	10.12	0.82	11.56	0.82
1.8	6.48	0.79	7.29	0.82	8.10	0.83	8.91	0.85	11.34	0.86	12.96	0.87
1.9	7.22	0.83	8.12	0.86	9.03	0.88	9.93	0.89	12.64	0.91	14.44	0.92
2.0	8.00	0.87	9.00	0.91	10.00	0.93	11.00	0.94	14.00	0.96	16.00	0.97
2.1	8.82	0.92	9.92	0.95	11.03	0.97	12.13	0.99	15.44	1.00	17.64	1.02
2.2	9.68	0.96	10.89	1.00	12.10	1.02	13.31	1.03	16.94	1.06	19.36	1.07
2.3	10.58	1.01	11.90	1.04	13.23	1.07	14.55	1.08	18.52	1.10	21.16	1.11
2.4	11.52	1.05	12.96	1.09	14.40	1.11	15.84	1.13	21.16	1.15	23.04	1.16
2.5	12.50	1.09	14.06	1.13	15.63	1.16	17.19	1.17	21.87	1.20	25.00	1.21
2.6	13.52	1.14	15.21	1.18	16.90	1.20	18.59	1.22	23.66	1.25	27.04	1.26
2.7	14.58	1.18	16.40	1.22	18.23	1.25	20.05	1.27	25.52	1.30	27.16	1.31
2.8	15.68	1.22	17.64	1.27	19.60	1.30	21.56	1.32	27.44	1.35	31.36	1.36
2.9	16.82	1.27	18.92	1.31	21.03	1.34	23.13	1.36	29.44	1.39	33.64	1.40
3.0	18.00	1.31	20.25	1.36	22.50	1.39	24.75	1.41	31.50	1.44	36.00	1.45

Table IV.C.4. Hydraulic radius (R) and area (A) of symmetrical trapezoidal channels [2′ bottom width].



$A = xd^2 + 2d$

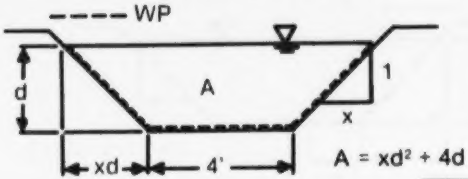
$WP = 2d\sqrt{1 + x^2} + 2$

$R = A/WP$

Depth, d (feet)	1:1		1½:1		2:1		2½:1		3:1		4:1	
	Slope ratio											
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	1.25	0.37	1.38	0.36	1.50	0.35	1.63	0.35	1.75	0.34	2.00	0.33
0.6	1.56	0.42	1.74	0.42	1.92	0.41	2.10	0.40	2.28	0.39	2.64	0.38
0.7	1.89	0.47	2.14	0.47	2.28	0.44	2.63	0.46	2.87	0.45	3.36	0.43
0.8	2.24	0.53	2.56	0.52	2.88	0.52	3.20	0.51	3.52	0.50	4.16	0.48
0.9	2.61	0.51	3.01	0.57	3.42	0.57	3.83	0.56	4.23	0.55	5.04	0.54
1.0	3.00	0.62	3.50	0.62	4.00	0.62	4.50	0.61	5.00	0.60	6.00	0.59
1.1	3.41	0.67	4.02	0.67	4.63	0.67	5.23	0.66	5.84	0.65	7.05	0.64
1.2	3.84	0.71	4.56	0.72	5.28	0.72	6.00	0.71	6.72	0.70	8.16	0.69
1.3	4.29	0.76	5.14	0.77	5.98	0.77	6.83	0.76	7.67	0.75	9.36	0.74
1.4	4.76	0.80	5.74	0.81	6.72	0.81	7.70	0.81	8.68	0.80	10.64	0.79
1.5	5.25	0.84	6.38	0.86	7.50	0.86	8.63	0.86	9.75	0.85	12.00	0.84
1.6	5.76	0.88	7.04	0.91	8.32	0.91	9.60	0.90	10.88	0.90	13.44	0.88
1.7	6.29	0.92	7.74	0.95	9.18	0.96	10.63	0.95	12.07	0.95	14.96	0.93
1.8	6.84	0.96	8.46	1.00	10.08	1.00	11.70	1.00	13.32	1.00	16.56	0.98
1.9	7.41	1.00	9.22	1.04	11.02	1.05	12.83	1.05	14.63	1.04	18.24	1.03
2.0	8.00	1.04	10.00	1.09	12.00	1.10	14.00	1.10	16.00	1.09	20.00	1.08
2.5	11.25	1.24	14.38	1.30	17.50	1.33	20.63	1.33	23.75	1.33	30.00	1.33
3.0	15.00	1.43	19.50	1.52	24.00	1.56	28.30	1.57	33.00	1.57	42.00	1.57

	5:1		6:1		7:1		8:1		9:1		10:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	2.25	0.32	2.50	0.31	2.75	0.30	3.00	0.30	3.25	0.29	3.50	0.29
0.6	3.00	0.37	3.36	0.36	3.72	0.35	4.08	0.35	4.44	0.34	4.80	0.34
0.7	3.85	0.42	4.34	0.41	4.83	0.41	5.32	0.40	5.81	0.39	6.30	0.39
0.8	4.80	0.47	5.44	0.46	6.08	0.46	6.72	0.45	7.36	0.45	8.00	0.44
0.9	5.85	0.52	6.66	0.51	7.47	0.51	8.28	0.50	9.09	0.50	9.90	0.49
1.0	7.00	0.51	8.00	0.56	9.00	0.56	10.00	0.55	11.00	0.55	12.00	0.54
1.1	8.25	0.62	9.47	0.62	10.68	0.61	11.89	0.60	13.10	0.60	14.31	0.59
1.2	9.60	0.67	11.04	0.67	12.48	0.66	13.92	0.65	15.36	0.65	16.80	0.64
1.3	11.05	0.72	12.74	0.72	14.43	0.71	16.12	0.70	17.81	0.70	19.50	0.69
1.4	12.60	0.77	14.50	0.77	16.52	0.76	18.48	0.75	20.44	0.75	22.40	0.74
1.5	14.25	0.82	16.50	0.81	18.75	0.81	21.00	0.80	23.25	0.80	25.50	0.79
1.6	16.00	0.87	18.56	0.86	21.12	0.86	23.68	0.85	26.24	0.85	28.80	0.84
1.7	17.85	0.92	20.74	0.91	23.63	0.91	26.52	0.90	29.41	0.90	32.30	0.89
1.8	19.80	0.97	23.04	0.96	26.28	0.96	29.52	0.95	32.76	0.95	36.00	0.94
1.9	21.85	1.02	25.46	1.01	29.07	1.01	32.68	1.00	36.29	1.00	39.90	0.99
2.0	24.00	1.07	28.00	1.06	32.00	1.06	36.00	1.05	40.00	1.05	44.00	1.04
2.5	36.25	1.32	42.50	1.31	48.75	1.30	55.00	1.30	61.25	1.30	67.50	1.29
3.0	51.00	1.56	60.00	1.56	69.00	1.55	78.00	1.55	87.00	1.54	96.00	1.54

Table IV.C.4.—Continued



$A = xd^2 + 4d$

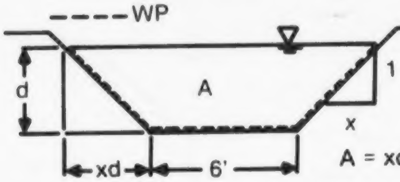
$WP = 2d\sqrt{1 + x^2} + 4$

$R = A/WP$

Depth, d (feet)	Slope ratio											
	1:1		1½:1		2:1		2½:1		3:1		4:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	2.25	0.41	2.38	0.41	2.50	0.40	2.63	0.39	2.75	0.39	3.00	0.37
0.6	2.76	0.48	2.94	0.48	3.12	0.47	3.30	0.46	3.48	0.45	3.84	0.43
0.7	3.29	0.55	3.54	0.54	3.78	0.53	4.03	0.52	4.27	0.50	4.76	0.49
0.8	3.84	0.61	4.16	0.60	4.48	0.59	4.80	0.58	5.12	0.57	5.76	0.54
0.9	4.41	0.67	4.82	0.66	5.22	0.65	5.63	0.64	6.03	0.62	6.84	0.60
1.0	5.00	0.73	5.50	0.72	6.00	0.71	6.50	0.69	7.00	0.68	8.00	0.65
1.1	5.61	0.79	6.22	0.78	6.82	0.76	7.43	0.75	8.03	0.73	9.24	0.71
1.2	6.24	0.84	6.96	0.84	7.68	0.82	8.40	0.80	9.12	0.79	10.56	0.76
1.3	6.89	0.90	7.74	0.89	8.58	0.87	9.43	0.86	10.27	0.84	11.96	0.81
1.4	7.56	0.95	8.54	0.94	9.52	0.93	10.50	0.91	11.48	0.89	13.44	0.86
1.5	8.25	1.00	9.38	1.00	10.50	0.98	11.63	0.96	12.75	0.94	15.00	0.92
1.6	8.96	1.05	10.24	1.05	11.52	1.03	12.80	1.01	14.08	1.00	16.64	0.97
1.7	9.69	1.10	11.14	1.10	12.58	1.08	14.03	1.07	15.47	1.05	18.36	1.02
1.8	10.44	1.15	12.06	1.15	13.68	1.14	15.30	1.12	16.92	1.10	20.16	1.02
1.9	11.21	1.20	13.02	1.20	14.82	1.19	16.63	1.17	18.43	1.15	22.04	1.12
2.0	12.00	1.24	14.00	1.25	16.00	1.24	18.00	1.22	20.00	1.20	24.00	1.17
2.5	16.25	1.47	19.38	1.48	22.50	1.48	25.63	1.47	28.75	1.45	35.00	1.42
3.0	21.00	1.68	25.50	1.72	30.00	1.72	34.50	1.71	39.00	1.70	48.00	1.67

	5:1		6:1		7:1		8:1		9:1		10:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	3.25	0.36	3.50	0.35	3.75	0.34	4.00	0.33	4.25	0.32	4.50	0.32
0.6	4.20	0.42	4.56	0.40	4.92	0.39	5.28	0.38	5.64	0.38	6.00	0.37
0.7	5.25	0.47	5.74	0.46	6.23	0.45	6.72	0.44	7.21	0.43	7.70	0.43
0.8	6.40	0.53	7.04	0.51	7.68	0.50	8.32	0.49	8.96	0.49	9.60	0.48
0.9	7.65	0.58	8.46	0.56	9.27	0.55	10.08	0.55	10.89	0.54	11.70	0.53
1.0	9.00	0.64	10.00	0.62	11.00	0.61	12.00	0.60	13.00	0.59	14.00	0.58
1.1	10.45	0.69	11.66	0.67	12.87	0.66	14.08	0.65	15.29	0.64	16.50	0.63
1.2	12.00	0.74	13.44	0.72	14.88	0.71	16.32	0.70	17.76	0.69	19.20	0.68
1.3	13.65	0.79	15.34	0.77	17.03	0.76	18.72	0.75	20.41	0.74	22.10	0.73
1.4	15.40	0.84	17.36	0.83	19.32	0.81	21.28	0.80	23.24	0.79	25.20	0.78
1.5	17.25	0.89	19.50	0.88	21.75	0.86	24.00	0.85	26.25	0.84	28.50	0.83
1.6	19.20	0.94	21.76	0.93	24.32	0.91	26.88	0.90	29.44	0.89	32.00	0.89
1.7	21.25	1.00	24.14	0.98	27.03	0.96	29.92	0.95	32.81	0.94	35.70	0.94
1.8	23.40	1.05	26.64	1.03	29.88	1.01	33.12	1.00	36.36	0.99	39.60	0.99
1.9	25.65	1.10	29.26	1.08	32.67	1.06	36.48	1.05	40.09	1.04	43.70	1.04
2.0	28.00	1.15	32.00	1.14	36.00	1.12	40.00	1.10	44.00	1.09	48.00	1.09
2.5	41.25	1.40	47.50	1.38	53.75	1.37	60.00	1.35	66.25	1.34	72.50	1.34
3.0	57.00	1.65	66.00	1.64	75.00	1.63	84.00	1.62	93.00	1.62	102.00	1.61

Table IV.C.4. —Continued



$$A = xd^2 + 6d$$

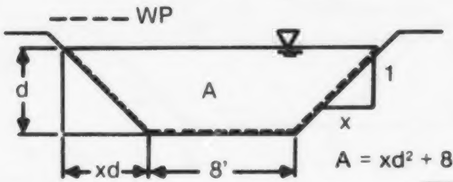
$$WP = 2d\sqrt{1 + x^2} + 6$$

$$R = A/WP$$

Depth, d (feet)	Slope ratio											
	1:1		1½:1		2:1		2½:1		3:1		4:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	3.25	0.44	3.38	0.43	3.50	0.42	3.63	0.42	3.50	0.41	4.00	0.40
0.6	3.96	0.51	4.14	0.51	4.32	0.50	4.50	0.49	4.68	0.48	5.04	0.46
0.7	4.69	0.59	4.94	0.58	5.18	0.57	5.43	0.56	5.67	0.54	6.16	0.52
0.8	5.44	0.66	5.76	0.65	6.08	0.63	6.40	0.62	6.72	0.61	7.36	0.58
0.9	6.21	0.73	6.62	0.72	7.02	0.70	7.43	0.68	7.83	0.67	8.64	0.64
1.0	7.00	0.79	7.50	0.78	8.00	0.76	8.50	0.75	9.00	0.73	10.00	0.70
1.1	7.81	0.86	8.42	0.85	9.02	0.83	9.63	0.80	10.23	0.79	11.44	0.76
1.2	8.64	0.92	9.36	0.91	10.08	0.89	10.80	0.87	11.52	0.85	12.96	0.82
1.3	9.49	0.98	10.34	0.97	11.18	0.95	12.03	0.93	12.87	0.91	14.56	0.87
1.4	10.36	1.04	11.34	1.03	12.32	1.00	13.30	0.98	14.28	0.96	16.24	0.93
1.5	11.25	1.10	12.38	1.08	13.50	1.06	14.63	1.04	15.75	1.01	18.00	0.98
1.6	12.16	1.16	13.44	1.14	14.72	1.12	16.00	1.09	17.28	1.07	19.84	1.03
1.7	13.09	1.22	14.54	1.20	15.98	1.17	17.43	1.15	18.87	1.13	21.76	1.09
1.8	14.04	1.27	15.66	1.25	17.28	1.23	18.90	1.20	20.52	1.18	23.76	1.14
1.9	15.01	1.32	16.82	1.30	18.62	1.28	20.43	1.25	22.23	1.24	25.84	1.19
2.0	16.00	1.37	18.00	1.36	20.00	1.34	22.00	1.31	24.00	1.29	28.00	1.24
2.5	21.25	1.61	24.38	1.61	27.50	1.60	30.63	1.58	33.75	1.55	40.00	1.50
3.0	27.00	1.86	31.50	1.87	36.00	1.85	40.50	1.83	45.00	1.80	54.00	1.76

	5:1		6:1		7:1		8:1		9:1		10:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	4.25	0.38	4.50	0.37	4.75	0.36	5.00	0.36	5.25	0.35	5.50	0.34
0.6	5.90	0.45	5.76	0.43	6.12	0.42	6.48	0.41	6.84	0.41	7.20	0.40
0.7	6.65	0.51	7.14	0.49	7.63	0.48	8.12	0.47	8.61	0.46	9.10	0.45
0.8	8.00	0.56	8.64	0.55	9.28	0.54	9.92	0.53	10.56	0.49	11.20	0.51
0.9	9.45	0.62	10.26	0.61	11.07	0.59	11.88	0.58	12.69	0.57	13.50	0.55
1.0	11.00	0.68	12.00	0.66	13.00	0.65	14.00	0.63	15.00	0.62	16.00	0.61
1.1	12.65	0.73	13.86	0.72	15.07	0.70	16.28	0.69	17.49	0.67	18.70	0.67
1.2	14.40	0.79	15.84	0.77	17.28	0.75	18.72	0.74	20.16	0.75	21.60	0.72
1.3	16.25	0.85	17.94	0.82	19.63	0.80	21.32	0.79	23.01	0.78	24.70	0.77
1.4	18.20	0.90	20.16	0.87	22.12	0.85	24.08	0.84	26.04	0.83	28.00	0.82
1.5	20.25	0.95	22.50	0.92	24.75	0.91	27.00	0.90	29.25	0.88	31.50	0.87
1.6	22.40	1.00	24.96	0.98	27.52	0.96	30.08	0.95	32.64	0.93	35.20	0.92
1.7	24.45	1.06	27.54	1.03	30.43	1.01	33.32	1.00	36.21	0.97	39.10	0.97
1.8	27.00	1.11	30.24	1.08	33.48	1.06	36.72	1.08	39.96	1.04	43.20	1.02
1.9	29.45	1.16	33.06	1.14	36.67	1.12	40.28	1.10	43.89	1.09	47.50	1.07
2.0	32.00	1.21	36.00	1.19	40.00	1.17	44.00	1.15	48.00	1.13	52.00	1.12
2.5	46.25	1.47	52.50	1.45	58.75	1.46	65.00	1.40	71.25	1.39	77.50	1.38
3.0	63.00	1.72	72.00	1.70	81.00	1.71	90.00	1.65	99.00	1.66	108.00	1.65

Table IV.C.4.—Continued



$A = xd^2 + 8d$

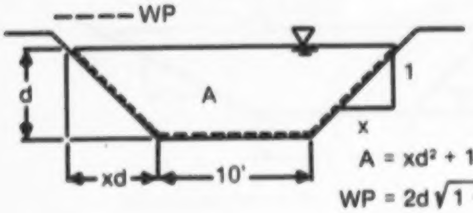
$WP = 2d\sqrt{1 + x^2} + 8$

$R = A/WP$

Depth,	Slope ratio											
d	1:1		1½:1		2:1		2½:1		3:1		4:1	
(feet)	A	R	A	R	A	R	A	R	A	R	A	R
0.5	4.25	0.45	4.38	0.45	4.50	0.44	4.63	0.43	4.75	0.43	5.00	0.41
0.6	5.16	0.53	5.34	0.53	5.52	0.52	5.70	0.51	5.88	0.50	6.24	0.48
0.7	6.09	0.61	6.34	0.60	6.58	0.59	6.83	0.58	7.07	0.57	7.56	0.55
0.8	7.04	0.69	7.36	0.68	7.68	0.66	8.00	0.65	8.32	0.64	8.96	0.61
0.9	8.01	0.76	8.42	0.75	8.82	0.73	9.22	0.72	9.63	0.70	10.44	0.68
1.0	9.00	0.83	9.50	0.82	10.00	0.80	10.50	0.78	11.00	0.77	12.00	0.74
1.1	10.01	0.90	10.62	0.89	11.22	0.87	11.83	0.85	12.43	0.83	13.64	0.80
1.2	11.04	0.97	11.76	0.95	12.48	0.93	13.20	0.91	13.92	0.89	15.36	0.86
1.3	12.09	1.04	12.94	1.02	13.78	1.00	14.63	0.98	15.97	0.95	17.16	0.92
1.4	13.16	1.10	14.14	1.08	15.12	1.06	16.10	1.04	17.08	1.01	19.04	0.97
1.5	14.25	1.16	15.38	1.14	16.50	1.12	17.63	1.10	18.75	1.07	21.00	1.03
1.6	15.36	1.23	16.64	1.21	17.92	1.18	19.20	1.16	20.48	1.13	23.04	1.09
1.7	16.49	1.29	17.44	1.27	19.38	1.24	20.83	1.22	22.27	1.19	25.16	1.14
1.8	17.64	1.35	19.26	1.33	20.88	1.30	22.50	1.27	29.12	1.24	27.36	1.20
1.9	18.81	1.41	20.63	1.40	22.42	1.36	24.23	1.33	26.03	1.30	29.64	1.25
2.0	20.00	1.46	22.00	1.45	24.00	1.42	26.00	1.39	28.00	1.36	32.00	1.31
2.5	26.25	1.76	29.38	1.72	32.50	1.69	35.63	1.66	38.75	1.63	45.00	1.57
3.0	33.00	2.00	37.50	1.99	42.00	1.96	46.50	1.93	51.00	1.89	60.00	1.83

	5:1		6:1		7:1		8:1		9:1		10:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	5.25	0.40	5.50	0.39	5.75	0.38	6.00	0.37	6.25	0.36	6.50	0.36
0.6	6.00	0.47	6.96	0.44	7.32	0.44	7.68	0.43	8.04	0.43	8.40	0.42
0.7	8.05	0.53	8.54	0.52	9.03	0.50	9.52	0.49	10.01	0.48	10.50	0.48
0.8	9.60	0.59	10.24	0.58	10.88	0.56	11.20	0.54	12.16	0.54	12.80	0.53
0.9	11.25	0.65	12.06	0.64	12.87	0.63	13.68	0.61	14.49	0.60	15.30	0.59
1.0	13.00	0.71	14.00	0.70	15.00	0.68	16.00	0.66	17.00	0.65	18.00	0.64
1.1	14.85	0.77	16.06	0.75	17.27	0.73	18.48	0.72	16.96	0.71	20.90	0.69
1.2	16.80	0.83	18.24	0.81	19.68	0.79	21.12	0.77	22.56	0.76	24.00	0.74
1.3	18.85	0.88	20.54	0.86	22.23	0.84	23.92	0.83	25.61	0.81	27.30	0.79
1.4	21.00	0.92	22.96	0.91	24.92	0.90	26.88	0.88	28.84	0.86	30.80	0.84
1.5	23.25	1.00	25.50	0.97	27.75	0.95	30.00	0.93	32.25	0.92	34.50	0.90
1.6	25.60	1.05	28.16	1.03	30.72	1.00	33.28	0.98	35.84	0.97	38.40	0.96
1.7	28.25	1.11	30.94	1.08	33.85	1.06	36.72	1.04	39.61	1.02	42.50	1.01
1.8	30.60	1.16	33.84	1.13	37.08	1.11	40.32	1.08	43.56	1.07	46.80	1.06
1.9	33.25	1.22	36.86	1.18	40.47	1.16	44.08	1.14	47.69	1.12	51.30	1.11
2.0	36.00	1.28	40.00	1.24	44.00	1.21	48.00	1.19	52.00	1.18	56.00	1.16
2.5	57.25	1.54	57.50	1.50	63.75	1.48	70.00	1.45	76.25	1.43	82.50	1.42
3.0	69.00	1.80	78.00	1.77	87.00	1.74	96.00	1.70	105.00	1.70	114.00	1.69

Table IV.C.4.—Continued



$A = xd^2 + 10d$

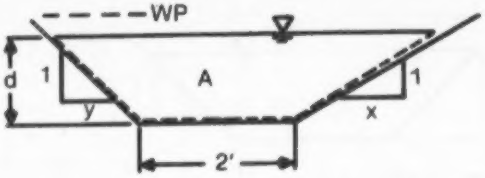
$WP = 2d\sqrt{1 + x^2} + 10$

$R = A/WP$

Depth, d (feet)	Slope ratio											
	1:1		1½:1		2:1		2½:1		3:1		4:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	5.25	0.46	5.38	0.46	5.50	0.45	5.63	0.44	5.75	0.44	6.00	0.42
0.6	6.36	0.54	6.54	0.54	6.72	0.53	6.90	0.52	7.08	0.51	7.44	0.50
0.7	7.49	0.63	7.74	0.62	7.98	0.61	8.23	0.60	8.47	0.59	8.96	0.57
0.8	8.64	0.71	8.96	0.70	9.28	0.68	9.60	0.67	9.92	0.66	10.56	0.64
0.9	9.81	0.78	10.22	0.77	10.62	0.76	11.03	0.74	11.43	0.73	12.24	0.70
1.0	11.00	0.86	11.50	0.85	12.00	0.83	12.50	0.81	13.00	0.80	14.00	0.77
1.1	12.21	0.93	12.82	0.92	13.42	0.90	14.03	0.88	14.63	0.86	15.84	0.83
1.2	13.44	1.00	14.16	0.99	14.88	0.97	15.60	0.95	16.32	0.93	17.76	0.89
1.3	14.69	1.07	15.54	1.06	16.38	1.04	17.23	1.01	18.07	0.99	19.76	0.95
1.4	15.96	1.14	16.94	1.13	17.92	1.10	18.90	1.08	19.88	1.05	21.84	1.01
1.5	17.25	1.21	18.38	1.19	19.50	1.17	20.63	1.14	21.75	1.12	24.00	1.07
1.6	18.56	1.28	19.84	1.26	21.12	1.23	22.40	1.20	23.68	1.18	26.24	1.13
1.7	19.89	1.34	21.34	1.32	22.78	1.29	24.23	1.26	25.67	1.24	28.56	1.19
1.8	21.24	1.41	22.86	1.39	24.48	1.36	26.10	1.33	27.72	1.30	30.96	1.25
1.9	22.61	1.47	24.42	1.45	26.22	1.42	28.03	1.39	29.83	1.35	33.44	1.30
2.0	24.00	1.53	26.00	1.51	28.00	1.48	30.00	1.44	32.00	1.41	36.00	1.36
2.5	31.25	1.83	34.38	1.81	37.50	1.77	40.63	1.73	43.75	1.69	50.00	1.63
3.0	39.00	2.11	43.50	2.09	48.00	2.05	52.50	2.01	57.00	1.97	66.00	1.90

	5:1		6:1		7:1		8:1		9:1		10:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	6.25	0.41	6.50	0.40	6.75	0.40	7.00	0.39	7.25	0.38	7.50	0.37
0.6	7.80	0.48	8.16	0.47	8.52	0.46	8.88	0.45	9.24	0.44	9.60	0.44
0.7	9.45	0.55	9.94	0.54	10.43	0.52	10.92	0.51	11.41	0.50	11.90	0.49
0.8	11.20	0.62	11.84	0.60	12.48	0.59	13.12	0.57	13.76	0.56	14.40	0.55
0.9	13.05	0.68	13.86	0.66	14.67	0.65	15.48	0.63	16.29	0.62	17.10	0.61
1.0	15.00	0.74	16.00	0.72	17.00	0.70	18.00	0.69	19.00	0.68	20.00	0.66
1.1	17.05	0.80	18.26	0.78	19.47	0.76	20.68	0.75	21.89	0.73	23.00	0.72
1.2	19.20	0.86	20.64	0.84	22.08	0.82	23.52	0.80	24.96	0.79	26.40	0.77
1.3	21.45	0.92	23.14	0.90	24.83	0.87	26.52	0.86	28.21	0.84	29.90	0.83
1.4	23.80	0.98	25.76	0.95	27.72	0.93	29.68	0.91	31.64	0.89	33.60	0.88
1.5	26.25	1.04	28.50	1.01	30.75	0.99	33.00	0.97	35.25	0.95	37.50	0.93
1.6	28.80	1.10	31.36	1.06	33.92	1.04	36.48	1.02	39.04	1.00	41.60	0.99
1.7	31.45	1.15	34.34	1.12	37.23	1.09	40.12	1.07	43.01	1.05	45.90	1.04
1.8	34.20	1.21	37.44	1.17	40.68	1.15	43.92	1.13	47.16	1.11	50.40	1.09
1.9	37.05	1.26	40.66	1.23	44.27	1.20	47.88	1.18	51.49	1.16	55.10	1.14
2.0	40.00	1.32	44.00	1.28	48.00	1.25	52.00	1.23	56.00	1.21	60.00	1.20
2.5	56.25	1.58	62.50	1.55	68.75	1.52	75.00	1.49	81.25	1.47	87.50	1.45
2.0	75.00	1.85	84.00	1.81	93.00	1.77	102.00	1.75	111.00	1.73	120.00	1.71

Table IV.C.5. Hydraulic radius (R) and area (A) of nonsymmetrical trapezoidal channels [2' bottom width].



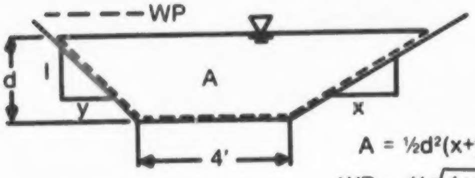
$$A = \tfrac{1}{2}d^2(x+y) + 2d$$

$$WP = d(\sqrt{1+y^2} + \sqrt{1+x^2}) + 2$$

$$R = A/WP$$

Depth, d (feet)	Slope ratio											
	1:1 - 3:1		1½:1 - 3:1		2:1 - 3:1		2½:1 - 3:1		4:1 - 3:1		5:1 - 3:1	
	A	R	A	R	A	R	A	R	A	R	A	R
1.0	4.00	0.61	4.25	0.61	4.50	0.61	4.75	0.61	5.50	0.59	6.00	0.58
1.1	4.62	0.66	4.92	0.66	5.23	0.66	5.53	0.66	6.44	0.64	7.04	0.63
1.2	5.28	0.70	5.64	0.71	6.00	0.71	6.36	0.70	7.44	0.68	8.16	0.68
1.3	5.98	0.75	6.40	0.76	6.83	0.76	7.25	0.75	8.52	0.73	9.36	0.74
1.4	6.72	0.80	7.21	0.80	7.70	0.81	8.19	0.81	9.66	0.79	10.64	0.79
1.5	7.50	0.85	8.06	0.85	8.63	0.85	9.19	0.85	10.88	0.84	12.00	0.84
1.6	8.32	0.89	8.96	0.91	9.60	0.91	10.24	0.90	12.16	0.90	13.44	0.88
1.7	9.18	0.94	9.90	0.95	10.63	0.95	11.35	0.95	13.52	0.94	14.96	0.93
1.8	10.08	0.99	10.89	1.00	11.90	1.01	12.51	1.00	14.94	0.98	16.56	0.98
1.9	11.02	1.03	11.92	1.04	12.83	1.05	13.73	1.05	16.44	1.03	18.24	1.03
2.0	12.00	1.07	13.00	1.09	14.00	1.10	15.00	1.10	18.00	1.09	20.00	1.08
2.2	14.08	1.17	15.29	1.19	16.50	1.19	17.71	1.19	21.34	1.19	23.76	1.18
2.4	16.32	1.26	17.76	1.28	19.20	1.28	20.64	1.29	24.96	1.28	27.84	1.27
2.6	18.72	1.35	20.41	1.37	22.10	1.37	23.79	1.38	28.86	1.38	32.24	1.37
2.8	21.28	1.43	23.24	1.46	25.20	1.48	27.16	1.48	33.04	1.48	36.76	1.48
3.0	24.00	1.52	26.25	1.54	28.50	1.57	30.75	1.57	37.50	1.57	42.00	1.57
3.5	31.50	1.76	34.57	1.78	37.63	1.80	40.70	1.81	49.88	1.81	56.01	1.81
4.0	40.00	1.97	44.00	2.00	48.00	2.02	52.00	2.03	64.00	2.04	72.00	2.04

Table IV.C.5.—Continued



$$A = \tfrac{1}{2}d^2(x+y) + 4d$$

$$WP = d(\sqrt{1+y^2} + \sqrt{1+x^2}) + 4$$

$$R = A/WP$$

Depth, d (feet)	Slope ratio											
	1:1 - 3:1		1½:1 - 3:1		2:1 - 3:1		2½:1 - 3:1		4:1 - 3:1		5:1 - 3:1	
	A	R	A	R	A	R	A	R	A	R	A	R
1.0	6.00	0.70	6.25	0.69	6.50	0.69	6.75	0.68	7.50	0.66	8.00	0.65
1.1	6.82	0.75	7.12	0.75	7.43	0.75	7.73	0.74	8.64	0.72	9.24	0.70
1.2	7.68	0.80	8.04	0.80	8.40	0.81	8.76	0.79	9.84	0.78	10.56	0.76
1.3	8.58	0.86	9.00	0.86	9.43	0.85	9.85	0.85	11.12	0.81	11.96	0.81
1.4	9.52	0.91	10.01	0.91	10.59	0.92	10.99	0.90	12.46	0.88	13.44	0.87
1.5	10.50	0.97	11.06	0.97	11.63	0.96	12.19	0.95	13.88	0.93	15.00	0.92
1.6	11.52	1.02	12.16	1.02	12.80	1.01	13.44	1.00	15.36	0.98	16.64	0.96
1.7	12.58	1.06	13.30	1.07	14.03	1.07	14.75	1.06	16.92	1.04	18.36	1.01
1.8	13.38	1.10	14.49	1.12	15.50	1.13	16.11	1.11	18.54	1.08	20.16	1.07
1.9	14.82	1.17	15.72	1.17	16.63	1.17	17.53	1.16	20.24	1.13	22.04	1.12
2.0	16.00	1.22	17.00	1.22	18.00	1.22	19.00	1.21	22.00	1.18	24.00	1.17
2.2	18.48	1.31	19.69	1.32	20.90	1.32	22.11	1.31	25.74	1.29	28.16	1.27
2.4	21.12	1.41	22.56	1.42	24.00	1.41	25.44	1.41	29.76	1.38	32.64	1.37
2.6	23.92	1.51	25.61	1.51	27.30	1.51	28.99	1.51	34.06	1.49	37.44	1.47
2.8	26.88	1.60	28.84	1.61	30.80	1.62	32.76	1.61	38.64	1.59	42.36	1.57
3.0	30.00	1.69	32.25	1.71	34.50	1.71	36.75	1.71	43.50	1.68	48.00	1.66
3.5	38.50	1.93	41.57	1.94	44.63	1.95	47.70	1.95	56.88	1.93	63.07	1.92
4.0	48.00	2.15	52.00	2.17	56.00	2.18	60.00	2.18	72.00	2.16	80.00	2.15

Chapter V

SOIL MASS MOVEMENT

this chapter was prepared by the following individuals:

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INTRODUCTION

Accurate models and the data needed to predict soil mass movement hazard and magnitude of delivery to stream courses over broad areas are currently lacking. Existing techniques for site specific stability analyses (based on the Mohr-Coulomb Theory of Earth Failure) are quite accurate in assessing the strength-stress relationships in a small area. These techniques, however, require accurate measurement of the engineering properties of the soils involved and specific knowledge of the geology and ground water hydrology at the site. Such data are costly to obtain and vary greatly among sites, even under the same geologic and climatic settings, making this mechanistic approach impractical for broad area hazard assessment.

A more practical approach is to combine:

1. A subjective evaluation of the relative stability of an area using soils, geologic, topographic, climatic, and vegetative indicators obtained from aerial photos, maps, and field observations.
2. A limited strength-stress analysis of the unstable sites using available or easily generated field data.
3. Estimates of sediment delivery to streams based on failure type, distance from the stream channel, and certain site variables such as slope gradient and slope irregularity.

This information can be integrated to provide a measure of mass movement hazard and the level of sediment contributed to adjacent stream channels.

Such an approach is developed in this chapter to provide a uniform framework for slope stability assessment and estimation of sediment delivery to channels by soil mass movement. A flow chart of this procedure is presented in figure V.1.

The primary objectives of the procedure are to determine: (1) natural stability of the site, (2) the sensitivity of the site to natural and man-induced soil mass movement events (the hazard index of soil mass movement generation or acceleration), (3) the probable volume of material released by soil mass movement, and (4) the amount of soil mass movement material delivered to the nearest drainageway.

Several common site and climatic factors which vary greatly over a wide region are related to soil mass movements. To provide for continuity over multiple geographic areas, the major factors controlling slope stability are summarized here by dominant failure types and placed in a framework of hazard index analysis.

If the user does not have experience in delineating potential soil mass movement sites, additional assistance will be required from specialists in the allied fields of geology, geotechnical engineering, and soil science. Users are strongly advised to seek assistance from these specialists whenever possible.

This chapter examines two groups of erosion processes: (1) rapid, shallow soil mass movements, collectively termed "debris avalanches-debris flows", but including a broad range of processes such as debris slides and rapid mudflows (Varnes 1958); and (2) slow, deep-seated soil mass movements, termed "slumps" and "earthflows" or collectively "slump-earthflows." These mass movement processes are described further in the section, "Principals and Interpretations of Soil Mass Movement Processes."

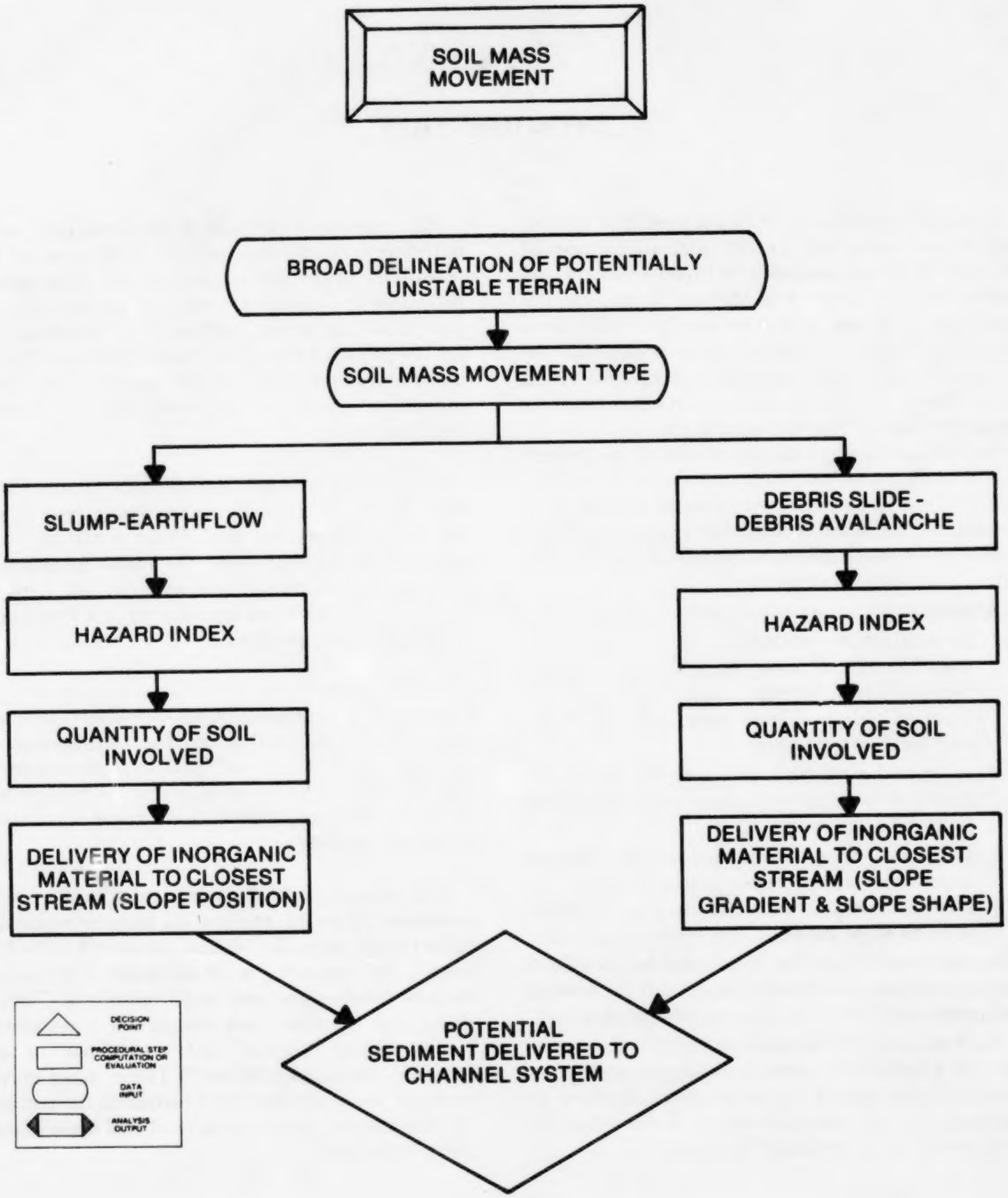

SOIL MASS MOVEMENT
BROAD DELINEATION OF POTENTIALLY UNSTABLE TERRAIN
SOIL MASS MOVEMENT TYPE
SLUMP-EARTHFLOW
DEBRIS SLIDE - DEBRIS AVALANCHE
HAZARD INDEX
HAZARD INDEX
QUANTITY OF SOIL INVOLVED
QUANTITY OF SOIL INVOLVED
DELIVERY OF INORGANIC MATERIAL TO CLOSEST STREAM (SLOPE POSITION)
DELIVERY OF INORGANIC MATERIAL TO CLOSEST STREAM (SLOPE GRADIENT & SLOPE SHAPE)
POTENTIAL SEDIMENT DELIVERED TO CHANNEL SYSTEM
DECISION POINT
PROCEDURAL STEP COMPUTATION OR EVALUATION
DATA INPUT
ANALYSIS OUTPUT

Figure V.1.—General flow chart of the soil mass movement procedure.

DISCUSSION

REVIEW OF RELEVANT WORK

Although quantitative assessment of all factors contributing to mass movement is complex and difficult, a consistent analysis of the major contributing factors can benefit the land manager, whose activities may affect slope stability. Burroughs and others (1976) discuss the effects of geology and structure in northern California and western Oregon on landslides generated by road construction; Swanston and Swanson (1976) describe the effects of geomorphology, climate, and forest management activities on debris avalanche and slump-earthflow activity in the western Cascades; Greswel, and others (in press) have assessed the effects of clearcut logging and road construction on accelerated debris avalanche activity during a single high intensity storm in the Oregon Coast Range; Burroughs and Thomas (1977) have analyzed the declining root strength in Douglas-fir, after felling, as a factor in slope stability; and Flaccus (1958), Hack and Goodlet (1969), and Williams and Guy (1973) discuss the effects of hurricane and cloudburst triggered soil mass movement in the eastern United States.

Some interesting and successful techniques also have been developed for predicting unstable ground and identifying controlling and contributing factors. Pillsbury (1976), for example, using a linear discriminant functions analysis, attributed 90.5 percent of the debris avalanches in clearcut areas of a northern California watershed to the factors of slope percent and percent cover by dominant and understory vegetation. Both of these factors were determined by photogrammetric techniques with no ground control. An additional 1.5 percent of debris avalanche occurrences was determined by adding in the site factors of soil weathering and percent quartz in bedrock. Using photogrammetric procedures, Kojan, Foggin, and Rice (1972) were able to predict 84.4 percent of the debris slides following major storms in the Santa-Ynez-San Rafael Mountains, California, based on past landslide activity.

The factor of safety is commonly used as a quantitative expression of the hazard index of a soil mass movement. In soil mechanics, it is customary to express the balance of forces acting on a simple slope as:

$$\text{Factor of safety (F)} = \frac{\text{Resistance of the soil to failure (shear strength)}}{\text{Forces promoting failure (shear stress)}}$$

A safety factor of one (F=1) would indicate imminent failure. For broad land use planning purposes, this technique is valid only for rapid, shallow soil mass movements, such as debris avalanches and debris flows. Quantitative models utilizing this approach have been outlined in Swanson and others (1973), Brown and Sheu (1975), Bell and Swanston (1972), and Simons and Ward (1976). The difficulty in determining some of the factors (such as tensile strength of roots, location of the failure surface, and water table position for various storm intensities) has until recently, restricted the use of such models to highly instrumented sites where expensive investigations were warranted. New data and techniques are being developed, however, which are making these models more practical as land management tools.

Swanston (1972, 1973) has employed a factor of safety technique using a simplified infinite slope model to predict slope stability hazard and stratify lands according to management impact in southeast Alaska. This technique uses slope gradient as a prime hazard index. Bell and Keener (1977) have developed a method of predicting stable cut-slope heights based on the factor of safety analysis of natural slopes. Burroughs and Thomas (1977) have analyzed the effects of soil shear strength, slope gradient, soil depth, ground water rise, and root strength on stability hazard in the central Coast Range of Oregon. Prellwitz (1977) has made substantial progress in utilization of the factor of safety approach without the need for expensive site investigation. The equations account for buoyant density, fluctuating water tables, and moisture density.

Soil mass movements can yield substantial sediment. Megahan (1972) and Megahan and Kidd (1972a, 1972b) evaluated the effects of logging and road construction on high erosion hazard land in the Idaho Batholith. They report sediment yields 1.6 times greater from jammer logged sites than from undisturbed areas (they did not differentiate between surface erosion and soil mass movement). Soil mass movements from logging roads in the same area average 550 times greater than control areas. Swanston and Swanson (1976) report debris avalanche erosion rates 2 to 4 times greater from clearcuts and 25 to 344 times greater from roads than from undisturbed sites in selected areas of the Coast Range and Cascade Mountains of Oregon, Washington, and British Columbia.

Prediction of sediment yield from individual soil mass movement processes is not well documented. Individual failure release volumes are available for a few areas, but there is little information on how much of the total volume initially reaches the stream versus how much remains on the slope for slow release over time. A summary of average debris avalanche volume from six studies in the Pacific Northwest reveals a broad range in average volumes from area to area (Swanson and others 1977). For example, in the Mapleton Ranger District of the Oregon Coast Range, an area of steep, intricately dissected terrain with very shallow soil, average debris avalanche volume is less than 100 yd^3(76 m^3), whereas steep areas of lower drainage density and deeper soils have had debris avalanches averaging more than 1,000 yd^3(765 m^3). In the Mapleton area, Swanson and others (1977) estimated that 65 percent of the material moved by debris avalanches in forests entered streams.

Since sediment yield values for individual soil mass movements are very limited, a series of conceptual delivery curves were developed for this handbook to approximate the sediment transport potential of dominant soil mass movement processes. These curves are presented as first approximations only, and it may be necessary to develop specific delivery curves to more accurately represent local conditions. Delivery relations are needed to estimate sediment supply to streams where it will be routed through the channel network. The delivery curves in the analysis section were developed from studies of recent failures in the western Cascades and Coast Range of Oregon, and were based on estimates of the percent of material released during the initial failure that actually entered a stream. The site variables which appeared particularly sensitive to the amount of soil delivered to a drainageway were: slope gradient and slope irregularity for debris avalanche-debris flows, and slope position with respect to the closest drainageway for slump-earthflows.[1] Slump-earthflow failures not adjacent to streams, are not considered principal contributors to channel loading in this analysis since their potential impact on short-term sediment loading is negligible because of their low delivery efficiencies. Most of the sediment from mid- and upper-slope failures of this type remain on the slope following initial failure and is delivered to the channel over extended periods, mainly by surface erosion and creep.

ASSUMPTIONS

The procedures in this chapter are presented as a guide for assessing the stability of natural slopes, the potential impacts of silvicultural activities on slope stability, and predicting sediment contributions to drainageways from soil mass movements. In the absence of proven local techniques, these procedures will provide the best available estimates of soil mass movement. The procedures are not rigid. They are a frame of reference within which local data and variables may be applied to provide better estimates of relative soil stability and contributions by soil mass movement to nonpoint source pollution.

Because of the complex nature of processes and variables and the need to present the procedures in a format usable on an inter-regional basis, the following simplifying assumptions are necessary:

1. The determination of hazard index will be based on the assumption of a maximum 10-year return period, 24-hour rainfall (precipitation intensity/duration) as a potential storm event triggering mass movement. If slides in a particular region occur frequently, with storms less than a 10-year return period, the hazard evaluation should reflect this (i.e., a 10-year event is not necessary for a high hazard index).
2. A three-part hazard index will be used. The numerical ratings are subjective and depend on what is considered to be acceptable for a particular land management activity. For purposes of this analysis:
   a. "High hazard" means a greater than 66 percent chance for a soil mass movement within the area evaluated for a 10-year return period storm event.
   b. "Medium hazard" means a greater than 33 and less than 66 percent chance for a soil mass movement within the area evaluated for a 10-year return period storm event.

---

[1] *Swanston and Swanson, unpublished data.*

c. "Low hazard" means a less than 33 percent chance for a soil mass movement within the area evaluated for a 10-year return period storm event.

3. Large organic debris contributions to drainageways, resulting from soil mass movement are not considered in estimates of sediment delivery. Although large quantities of organic debris are incorporated in the total volume of material released to the channel by soil mass movement, much of it remains in the channel near the point of entry.
4. Sediment delivery to the stream can be estimated from relationships between failure type and slope gradient, slope position (point of origin of failure), and morphology of the surface.
5. Volume of sediment delivered to the channel per unit area is a more realistic measure of soil mass movement impact than is number of events.
6. The instructions provided for quantifying volumes can be readily applied by field scientists.
7. Processes of soil mass movement described at this broad planning level can be readily identified and characterized regardless of geographic location.
8. Only slump-earthflows and debris avalanches-debris flows will be used to evaluate direct, short-term contributions of sediment to streams.

   Each of these two categories have been identified and described on the basis of material characteristics, failure geometry, and mechanism of movement. These categories are most affected by silvicultural activities and have the greatest potential for short-term water quality degradation.
9. Surface erosion of landslide material remaining on the slope will be determined in another section which deals with surface erosion delivery to stream channels.
10. Debris torrents will not be evaluated directly. It is assumed that when the hazard is high for debris avalanches-debris flows, it will also be high for debris torrents.
11. Sediment delivered to streams from erosion caused by creep will not be directly evaluated because of the close interrelationships of the variables involved in both creep and slump-earthflow processes. Sediment contributions from creep will be indirectly assessed using the channel erosion processes evaluated in "Chapter VI: Total Potential Sediment".

PRINCIPLES AND INTERPRETATIONS OF SOIL MASS MOVEMENT PROCESSES

Silvicultural activities in mountainous regions, particularly forest harvest and road construction, can have a major impact on site erosion and can accelerate transport of soil materials downslope by soil mass movement. The resultant downstream damage from aggradation and degradation of the channel may cause bank erosion, disrupt aquatic habitat, and produce undesirable changes in estuarine configuration and habitat by siltation and channel alterations. This is particularly true for areas with steep slopes subject to high intensity rain and/or rapid snowmelt.

Where heavy forest vegetation covers the slope, the high infiltration capacity of the forest soils and covering organic materials generally protect the slopes from surface erosion. Under these conditions, soil mass movement processes are generally the dominant natural mechanisms of soil transport from mountain slopes to stream channels. Only where bare mineral soil is exposed by disturbance of the vegetative and organic litter cover, either by natural processes or silvicultural activities, does surface erosion significantly contribute to this slope transport process.

Principal Soil Mass Movement Processes

Downslope soil mass movements result primarily from gravitational stress. It may take the form of: (1) failure, both along planar and concave surfaces, of finite masses of soil and forest debris which move rapidly (debris avalanches-debris flows) or slowly (slump-earthflows) (fig. V.2); (2) pure rheological flow with minor mechanical shifting of mantle materials (creep); and (3) rapid movement of water-charged organic and inorganic matter down stream channels (debris torrents).

Slope gradient, soil depth, soil water content, and physical soil properties, such as cohesion and coefficient of friction, control the mechanics and rates of soil mass movement. Geological,

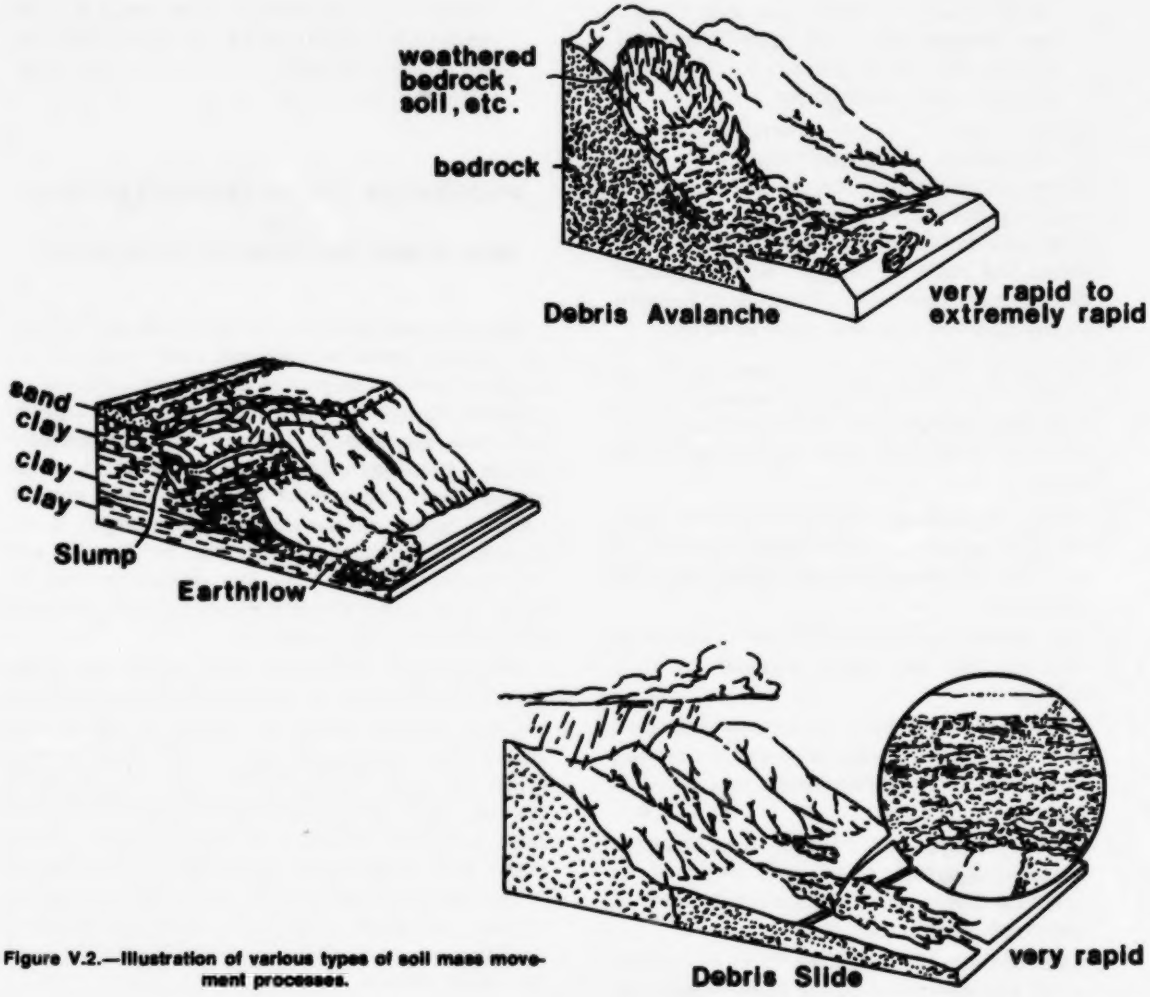


Figure V.2.—Illustration of various types of soil mass movement processes.

hydrological, and vegetative factors determine occurrence and relative importance of such processes in a particular area.

Slump-Earthflows

Where creep displacement has exceeded the shear strength of soil, discrete failure occurs and slump-earthflow features are formed (Varnes 1958). Simple slumping takes place as a rotational movement of a block of earth over a broadly concave slip surface and involves little breakup of the moving material. Where the moving material slips downslope and is broken up and transported either by a flowage mechanism or by gliding displacement of a series of blocks, the movement is termed slow earthflow (Varnes 1958) (fig. V.3). Geologic, vegetative, and hydrologic factors have primary control over slump-earthflow occurrence. Deep, cohesive soils and clay-rich bedrock are especially prone to slump-earthflow failure, particularly where these materials are overlain by hard, competent rock (Wilson 1970, Swanson and James 1975). Earthflow movement also appears to be sensitive to long-term fluctuations in soil water content (Wilson 1970, Swanston 1976).

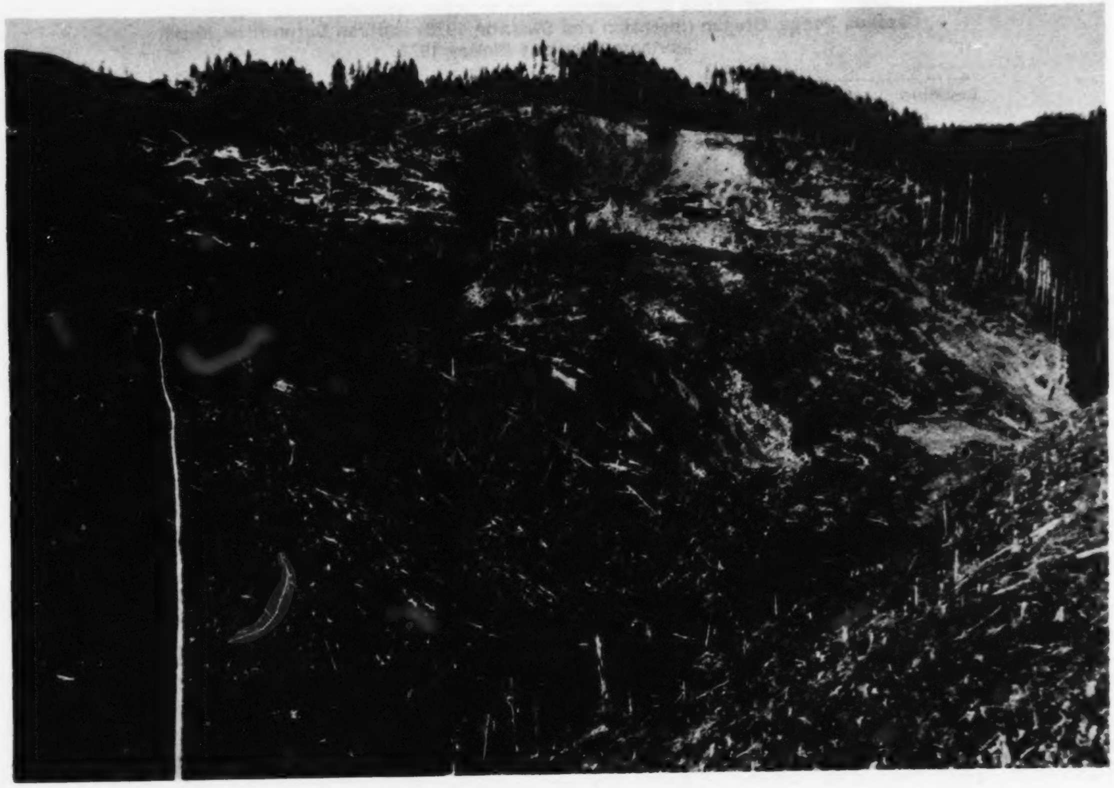


Figure V.3.—Slump and earthflow in deeply weathered sandstones and siltstones in the Oregon Coast Ranges. The slump occurred almost instantaneously. The resulting earthflow, over a period of several hours, dammed a perennial stream and produced the lake in the lower foreground.

Because earthflows are slowly moving, deep-seated, poorly drained features, individual storms probably have much less influence on their movement than on the likelihood of occurrence of debris avalanches-debris flows. Where planes of slump-earthflow are more than several meters deep, weight of vegetation and vertical root anchoring effects are insignificant.

Earthflows can move imperceptibly slowly to more than 1 m/day in extreme cases. In parts of northwest North America, many slump-earthflow areas appear to be inactive (Colman 1973, Swanson and James 1975). Where slump-earthflows are active, rates of movements have been monitored directly by repeated surveying of marked points and inclinometers and by measuring deflection of roadways and other inadvertent reference systems. These methods have been used to estimate the rates of earthflow movement shown in table V.1 (Swanston and Swanson 1976, Kelsey 1977).

The area of occurrence of slump-earthflows is mainly determined by bedrock geology. For example, in the Redwood Creek basin, northern California, Colman (1973) observed that of the 27.4 percent of the drainage which is in slumps, earthflows, and older or questionable soil mass movements, a very high percentage of the unstable areas are located in clay-rich and pervasively sheared sedimentary rocks. Areas underlain by schists and other more highly metamorphosed rock are much less prone to deep-seated soil mass movement. The area of occurrence of slump-earthflows in volcanic

Table V.1.—Observations of movement rates of active earthflows in the western Cascade Range, Oregon (Swanston and Swanson 1976) and Van Duzen River Basin, northern California (Kelsey 1977)

Location	Period of record	Movement rate	Method of observation
	years	cm/yr	
Landes Creek[1] (Sec.21 T.22S, R.4E.)	15	12	Deflection of road
Boone Creek[1] (Sec.17 T.17S, R.5E.)	2	25	Deflection of road
Cougar Reservoir[1] (Sec.29 T.17S, R.5E.)	2	2.5	Deflection of road
Lookout Creek[1] (Sec.30 T.15S, R.6E.)	1	7	Strain rhombus Measurements across active ground breaks
Donaker Earthflow[2] (Sec.10 T.1N, R.3E.)	1	60	Resurvey of stake line
Chimney Rock Earthflow[2] (Sec.30 T.2N, R.4E.)	1	530	Resurvey of stake line
Halloween Earthflow[2] (Sec.6 T.1N, R.5E.)	3	2,720	Resurvey of stake line

[1] Swanston and Swanson 1976.
[2] Kelsey 1977.

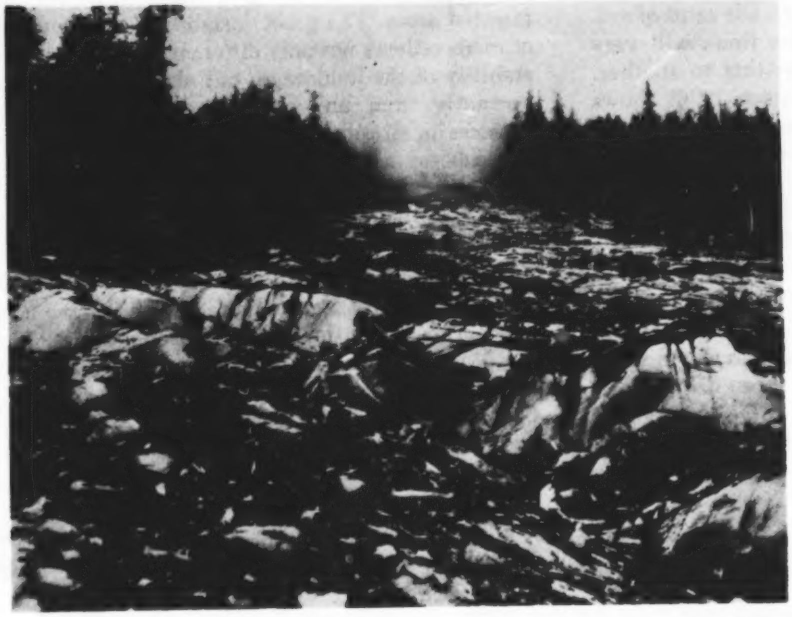
terrains has also been closely linked to bedrock (Swanston and Swanson 1976). There are numerous examples of accelerated or reactivated slump-earthflow movement after forest road construction in the western United States (Wilson 1970). Undercutting the toes of earthflows and piling rock and soil debris on slump blocks are common practices which influence slump-earthflow movement. Stability of such areas is also affected by modification of drainage systems, particularly where road drainage systems route additional water into the slump-earthflow areas. These disturbances may increase movement rates from a few millimeters per year to many centimeters. Once such areas have been destabilized, they may continue to move at accelerated rates for several years.

Although the impact of deforestation alone on slump-earthflow movement has not been demonstrated quantitatively, evidence suggests that it may be significant. In massive, deep-seated failures, lateral and vertical anchoring by tree root systems is negligible. Hydrologic impacts of deforestation, however, appear to be important. Reduced evapotranspiration will increase soil moisture availability. This water is, therefore, free to pass through the rooting zone to deeper levels of the earthflow.

Debris Avalanches-Debris Flows

Debris avalanches-debris flows are rapid, shallow soil mass movements from hillslope areas. Here the term "debris avalanche-debris flow" is used in a general sense encompassing debris slides, avalanches, and flows which have been distinguished by Varnes (1958) (fig. V. 4) and others on the basis of increasing water content and type of included material. From a land management standpoint, there is little purpose to differentiating among the types of shallow hillslope failures, since the mechanics and the controlling and contributing factors are the same. Areas prone to debris avalanches-debris flows are typified by shallow, noncohesive soils on steep slopes where subsurface water may be concentrated by subtle topography on bedrock or glacial till surfaces. Because debris avalanches-debris flows are shallow failures, factors such as root strength, anchoring effects, and the transfer of wind stress to the soil mantle are potentially important influence. Factors which influence antecedent soil moisture conditions and the rate of water supply to the soil during snowmelt and rainfall also have significant control over the time and place of debris avalanches-debris flows.

The rate of occurrence of debris avalanches-debris flows is controlled by the stability of the



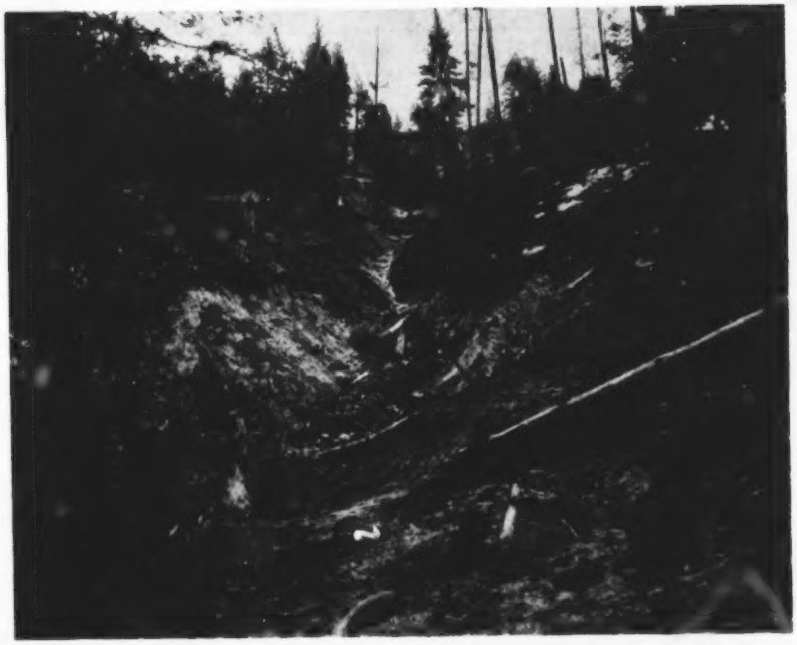


Figure V.4.—Debris avalanche and debris torrent development on steep forested watersheds in northwestern North America. (a.) Debris avalanche developed in shallow cohesionless soils on a steep, forested slope in coastal Alaska. (b.) Debris torrent developed in a steep gully, probably caused by failure of a natural debris dam above trees in foreground.

landscape and the frequency of storm events severe enough to trigger them. Therefore, the rates of erosion by debris avalanches-debris flows will vary from one geomorphic-climatic setting to another. Table V.2 (Swanston and Swanson 1976) shows that annual rates of debris avalanche erosion from forested study sites in Oregon and Washington in the United States, and British Columbia in Canada, range from 11 to 72 m³/km²/yr. These estimates are based on surveys and measurements of debris avalanche erosion during a particular time period (15 to over 32 years) over a large area (12 km² or larger).

An analysis of harvesting impacts in the western United States (Swanston and Swanson 1976) (table V.2) reveals that timber harvesting commonly results in an acceleration of soil mass movement activity by a factor of 2 to 4 times relative to forested areas. In the four study areas listed in table V.2, road-related debris avalanche erosion was increased by factors ranging from 25 to 340 times the rate of debris avalanche erosion in forested areas. The great variability in the impact of roads reflects not only differences in the natural stability of the landscape, but also, and more importantly from an engineering standpoint, differences in site location, design, and construction of roads.

Soil Creep

Soil creep is defined as the slow, downslope movement of soil mantle materials as the result of long-term application of gravitational stress. The mechanics of soil creep have been investigated experimentally and theoretically (Terzaghi 1953, Goldstein and Ter-Stepanian 1957, Saito and Uezawa 1961, Culling 1963, Haefeli 1965, Bjerrum 1967, Carson and Kirkby 1972). Movement is quasi-viscous; it occurs under shear stresses sufficient to produce permanent deformation, but too small to result in discrete failure. Mobilization of

Table V.2.—Debris avalanche erosion in forest, clearcut, and roaded areas (Swanston and Swanson 1976)

Site	Period of record	--------Area	--------	Number of slides	Debris avalanche erosion	Rate of debris avalanche erosion relative to forested areas
	years	percent	km²		m³/km²/yr	
Stequaleho Creek, Olympic Peninsula, Washington, U.S.A. (Fiksdal 1974):						
Forest	84	79.0	9.3	25	71.8	1.0
Clearcut	6	18.0	4.4	0	0.0	0.0
Road	6	3.0	0.7	83	11,825.0	165.0
			24.4	108		
Alder Creek, Western Cascade Range, Oregon, U.S.A. (Morrison 1975):						
Forest	25	70.5	12.3	7	45.3	1.0
Clearcut	15	26.0	4.5	18	117.1	2.6
Road	15	3.5	0.6	75	15,565.0	344.0
			17.4	100		
Selected drainages, Coast Mountains, S.W. British Columbia, Canada:[1]						
Forest	32	83.9	246.1	29	11.2	1.0
Clearcut	32	9.5	26.4	18	24.5	2.2
Road	32	1.5	4.2	11	[1]282.5	25.2
			276.7	58		
H. J. Andrews Experimental Forest, western Cascade Range, Oregon, U.S.A. (Swanson and Dyrness 1975):						
Forest	25	77.5	49.8	31	35.9	1.0
Clearcut	25	19.3	12.4	30	132.2	3.7
Road	25	3.2	2.0	69	1,772.0	49.0
			64.2	130		

[1] Calculated from O'Loughlin (1972, and personal communication), assuming that area involving road construction in and outside clearcuts is 16 percent of area clearcut. Colin L. O'Loughlin, is now at Forest Research Institute, New Zealand Forest Service, Rangiora, New Zealand.

the soil mass is primarily by deformation at grain boundaries and within clay mineral structures. Both interstitial and absorbed water appear to contribute to creep movement by opening the structure within and between mineral grains, thereby reducing friction within the soil mass. Creeping terrain can be recognized by characteristic rolling, hummocky topography with frequent sag ponds, springs, and occasional benching due to local rotational slumping. Local discrete failures, such as debris avalanches and slump-earthflows, may be present within the creeping mass (fig. V.5).

Natural creep rates monitored in different geological materials in the western Cascade and Coast Ranges of Oregon and northern California indicate rates of movement between 7.1 and 15.2 mm/yr, with the average about 10 mm/yr (Swanston and Swanson 1976) (table V.3). The most rapid movement usually occurs at or near the surface, although the significant displacement may extend to variable depths associated with incipient failure planes or zones of ground water movement. Active creep depth varies greatly and largely depends on parent material origin, degree and depth of weathering, subsurface structure, and soil water content. Most movement appears to take place during rainy season maximum soil water levels (fig. V.6 a), although creep may remain constant throughout the year in areas where the water table does not undergo significant seasonal fluctuation (fig. V.6 b). This is consistent with Ter-Stepanian's (1963) theoretical analysis which shows that the downslope creep rate of an inclined soil layer is exponentially related to piezometric level in the slope.

There have been no direct measurements of the impact of deforestation on creep rates in the forest environment, mainly because of the long periods of records needed both before and after a disturbance. There are, however, a number of indications that creep rates are accelerated by harvesting and road construction.

In the United States, Wilson (1970) and others have used inclinometers to monitor accelerated creep following modification of slope angle, compaction of fill materials, and distribution of soil mass at construction sites. The common occurrence of shallow soil mass movements in these disturbed areas and open tension cracks in fills along roadways suggests that similar features along forest roads indicate significantly accelerated creep movement.

On open slopes where deforestation is the principal influence, impact on creep rates may be more subtle, involving modifications of hydrology and root strength. Where creep is a shallow phenomenon (less than several meters), the loss of

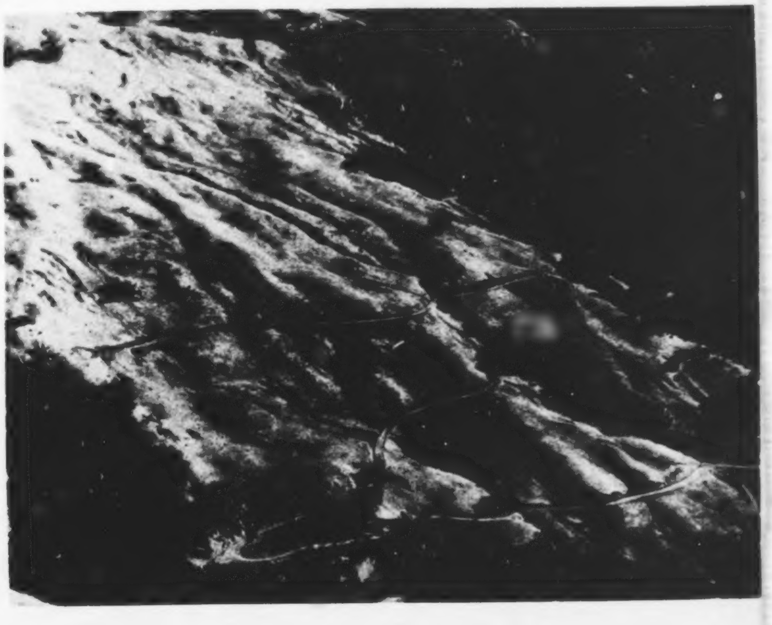
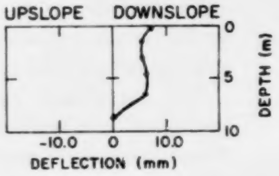
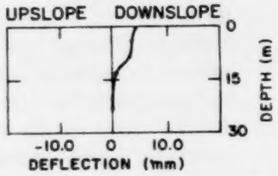
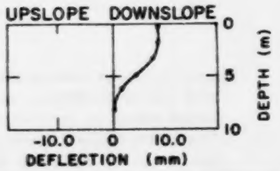
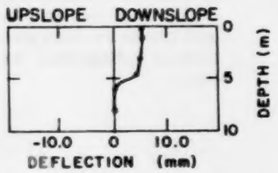


Figure V.5.—An example of soil creep and slump-earthflow processes on forest lands in northern California. The entire slope is undergoing creep deformation, but note the discrete failure (slump-earthflow) marked by the steep headwall scarp at top center and the many small slumps and debris avalanches triggered by surface springs and road construction.

Table V.3—Examples of measured rates of natural creep on forested slopes in the Pacific Northwest (Swanston and Swanson 1976)

Location	**Data source**	**Parent material**	**Depth of significant movement**	**Maximum downslope Creep rate**		**Representative creep profile**
				Surface	**Zone of accelerated movement**	
			m	mm/yr	mm/yr	
Coyote Creek, South Umpqua River drainage, Cascade Range of Oregon, Site C-1	Swanston[1]	Little Butte volcanic series; deeply weathered, clay-rich, andesitic dacitic, volcaniclastic rocks	7.3	13.97	10.9	
Blue River drainage - Lookout Creek, H. J. Andrews Exp, Forest, Central Cascades of Oregon, Site A-1	Swanston[1]	Little Butte volcanic series Same as above	5.6	7.9	7.1	
Blue River drainage, IBP Experimental Watershed 10, Site No. 4	McCorison[2] and Glenn	Little Butte volcanic series	0.5	9.0	---	
Baker Creek Coquille River Coast Range, Oregon Site B-3	Swanston[1]	Otter Point formation highly sheared and altered clay-rich argillite and mudstone	7.3	10.4	10.7	
Bear Creek Nestucca River Coast Range, Oregon Site N-1	Swanston[1]	Nestucca formation deeply weathered pyroclastic rocks and interbedded, shaley siltstones and claystones	15.2	14.9	11.7	

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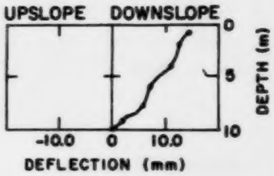
[1] Douglas N. Swanston, unpublished data on file at Forestry Sciences Laboratory, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oreg.

[2] F. Michael McCorison and L. F. Glenn, data on file at Forestry Sciences Laboratory, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oreg.

Table V.3—Examples of measured rates of natural creep on forested slopes in the Pacific Northwest (continued)

Redwood Creek Coast Range Northern California Site 3-B	Swanston[1]	Kerr Ranch schist sheared, deeply weathered clayey schist	2.6	15.2	10.4	

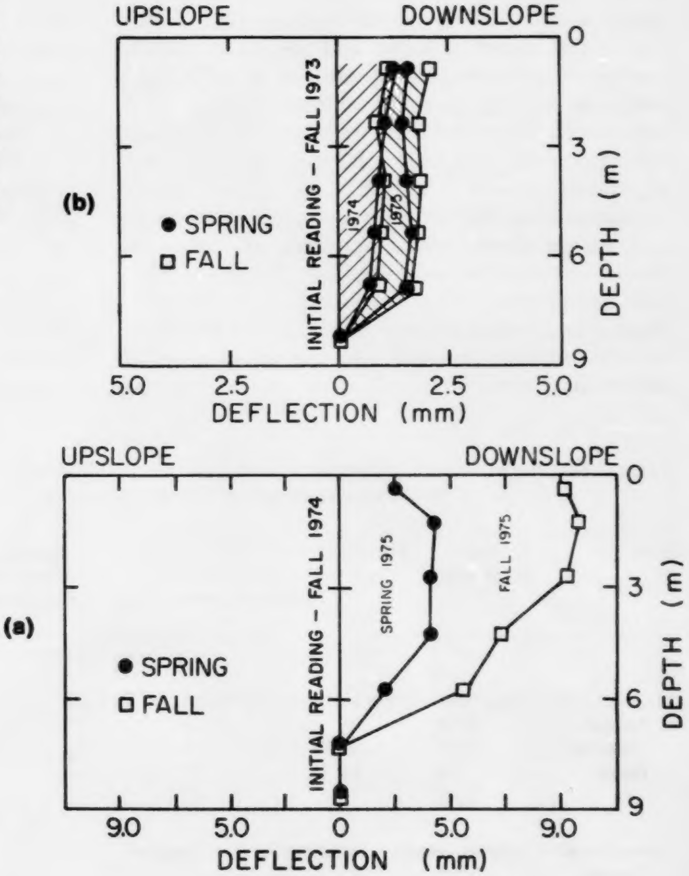


Figure V.6.—Deformation of inclinometer tubes at two sites in the southern Cascade and Coast Ranges of Oregon (Swanston and Swanson 1976). (a) Coyote Creek in the southern Cascade Range showing seasonal variation in movement rate as the result of changing soil water levels. Note that the difference in readings between spring and fall of each year (dry months) is very small. (b) Baker Creek, Coquille River, Oregon Coast Ranges, showing constant rate of creep as a result of continual high water levels.

root strength caused by deforestation is likely to be significant. Reduced evapotranspiration after clearcutting (Gray 1970, Rothacher 1971) may result in longer duration of the annual period of creep activity and, thereby, increase the annual creep rate.

Debris Torrents

Debris torrents involve the rapid movement of water-charged soil, rock, and organic material down steep stream channels. They typically occur in steep, intermittent, and first- and second-order channels. They are triggered during extreme discharge by debris avalanches from adjacent hillslopes which enter a channel and move directly downstream or by the breakup and mobilization of debris accumulations in the channel (fig. V.4b). The initial slurry of water and associated debris commonly entrains large quantities of additional inorganic and organic material from the streambed and banks. Some torrents are triggered by debris avalanches of less than 100 yd^3 (76 m^3), but ultimately involve 1,000 yd^3 (760 m^3) of debris entrained along the track of the torrent. As the torrent moves downstream, hundreds of meters of channel may be scoured to bedrock. When a torrent loses momentum, there is deposition of a tangled mass of large organic debris in a matrix of sediment and fine organic material covering areas of up to several hectares.

The main factors controlling the occurrence of debris torrents are the quantity and stability of debris in channels, steepness of channel, stability of adjacent hillslopes, and peak discharge characteristics of the channel. The concentration and stability of debris in channels reflect the history of stream flushing and the health and stage of development of the surrounding timber stand (Froehlich 1973). The stability of adjacent slopes depends on factors described in previous sections. The history of storm flows has a controlling influence over the stability of both soils on hillslopes and debris in stream channels.

Although debris torrents pose significant environmental hazards in mountainous areas of northwestern North America, they have received little study (Fredriksen 1963, 1965; Morrison 1975; Swanson and others 1976). Velocities of debris torrents, estimated to be up to several tens of meters/second, are known only from a few verbal and written accounts. Torrents have been systematically documented in only two small areas of the Pacific Northwest, both in the western Cascade Range of Oregon (Morrison 1975, Swanston and Swanson 1976). In these studies, rates of debris torrent occurrence were observed to be 0.005 and 0.008 events/km^2/yr for forested areas (table V.4). Torrent tracks initiated in forest areas ranged in length from 328 to 7,480 ft (100 to 2,280 m) and averaged 2,000 ft (610 m) of channel length. Debris avalanches have played a dominant role in triggering 83 percent of inventoried torrents

Table V.4—Characteristics of debris torrents with respect to debris avalanches[1] and land use status of initiation in the H. J. Andrews Experimental Forest[1] and Alder Creek Drainage (Morrison 1975)

Site	Area of watershed	Period of record	Debris torrents triggered by debris avalanches	Debris torrents with no associated debris avalanche	Total		Rate of debris torrent occurrence relative to forested areas
	km^2	yr	number			km^2/yr	
H. J. Andrews Experimental Forest, western Cascades, Oregon							
Forest	49.8	25	9	1	10	0.008	1.0
Clearcut	12.4	25	5	6	11	0.036	4.5
Road	2.0	25	17	-	17	0.340	42.0
	64.2		31	7	38		
Alder Creek drainage, western Cascade Range, Oregon							
Forest	12.3	90	5	1	6	0.005	1.0
Clearcut	4.5	15	2	1	3	0.044	8.8
Road	0.6	15	6	-	6	0.667	133.4
	17.4		13	2	15		

[1] Frederick J. Swanson, unpublished data, on file at Forestry Sciences Laboratory, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oreg.

(Swanston and Swanson 1976). Mobilization of stream debris not immediately related to debris avalanches has been a minor factor in initiating debris torrents in headwater streams.

Deforestation appears to dramatically accelerate the occurrence of debris torrents by increasing the frequency of debris avalanches. Although it has not been demonstrated, it is also possible that increased concentrations of unstable debris in channels during forest harvesting (Rothacher 1959, Froehlich 1973, Swanson and others 1976) and possible increased peak discharges (Rothacher 1973, Harr and others 1975) may accelerate the frequency of debris torrents.

The impact of clearcutting and road construction on frequency of debris torrents (events/km^2/yr) may be compared to debris torrent occurrence under natural conditions. In the H. J. Andrews Experimental Forest and the Alder Creek study sites in Oregon, timber harvesting appeared to increase occurrence of debris torrents by 4.5 and 8.8 times; and roads were responsible for increases of 42.5 and 133 times relative to forested areas.

Although the quantitative reliability of these estimates of harvesting impacts is limited by the small number of events analyzed, there is clear evidence of marked acceleration in the frequency of debris avalanches-debris flows as a result of forest harvesting and road building. The histories of debris avalanches-debris flows in the two study areas clearly indicate that increased debris torrent occurrence is primarily a result of two conditions: debris avalanches trigger most debris torrents (table V.4) and the occurrence of debris avalanches-debris flows is temporarily accelerated by deforestation and road construction (table V.2).

Mechanics of Movement

Direct application of soil mechanics theory to analysis of soil mass movement processes is difficult because of the heterogeneous nature of soil materials, the extreme variability of soil water conditions, and the related variations in stress-strain relationships with time. However, the theory provides a convenient framework for discussing the general mechanism and the complex interrelationships of the various factors active in development of soil mass movements on mountain slopes.

In terms of factor of safety analysis, the stability of soils on a slope can be expressed as a ratio between shear strength, or resistance of the soil to sliding, and the downslope pull of gravity or gravitational stress. As long as shear strength exceeds the pull of gravity, the soil will remain in a stable state (Terzaghi 1950, Zaruba and Mencl 1969).

It is important to remember that soil mass movements result from changes in the soil shear strength-gravitational stress relationship in the vicinity of failure. This may involve a mechanical readjustment among individual particles or a more complex interaction between both internal and external factors acting on the slope.

Figure V.7 shows the geometrical relationship of factors acting on a small portion of the soil mass. Any increases in gravitational stress will increase the tendency for the soil to move downslope. Increases in gravitational stress result from increasing inclination of the sliding surface or increasing unit weight of the soil mass. Stress can also be augmented by: (1) the presence of zones of weaknesses in the soil or underlying bedrock produced by bedding planes and fractures, (2) application of wind stresses transferred to the soil through the stems and root systems of trees, (3) strain or deformation in the soil produced by progressive creep, (4) frictional "drag" produced by seepage pressure, (5) horizontal accelerations due to earthquakes and blasting, and (6) removal of downslope support by undercutting.

Shear strength is governed by a more complex interrelationship between the soil and slope characteristics. Two principal forces are active in resisting downslope movement. These are: (1) cohesion or the capacity of the soil particles to adhere together, a soil property produced by cementation, capillary tension, or weak electrical bonding of organic colloids and clay particles; and (2) the frictional resistance between individual particles and between the soil mass and the sliding surface. Frictional resistance is controlled by the angle of internal friction of the soil — the degree of interlocking of individual grains — and the effective weight of the soil which includes both the weight of the soil mass and any surface loading plus the effect of slope gradient and excess soil water.

Pore water pressure — pressure produced by the head of water in saturated soil and transferred to the base of the soil through the pore water — acts to reduce the frictional resistance of the soil by reducing its effective weight. In effect, its action causes the soil to "float" above the sliding surface.

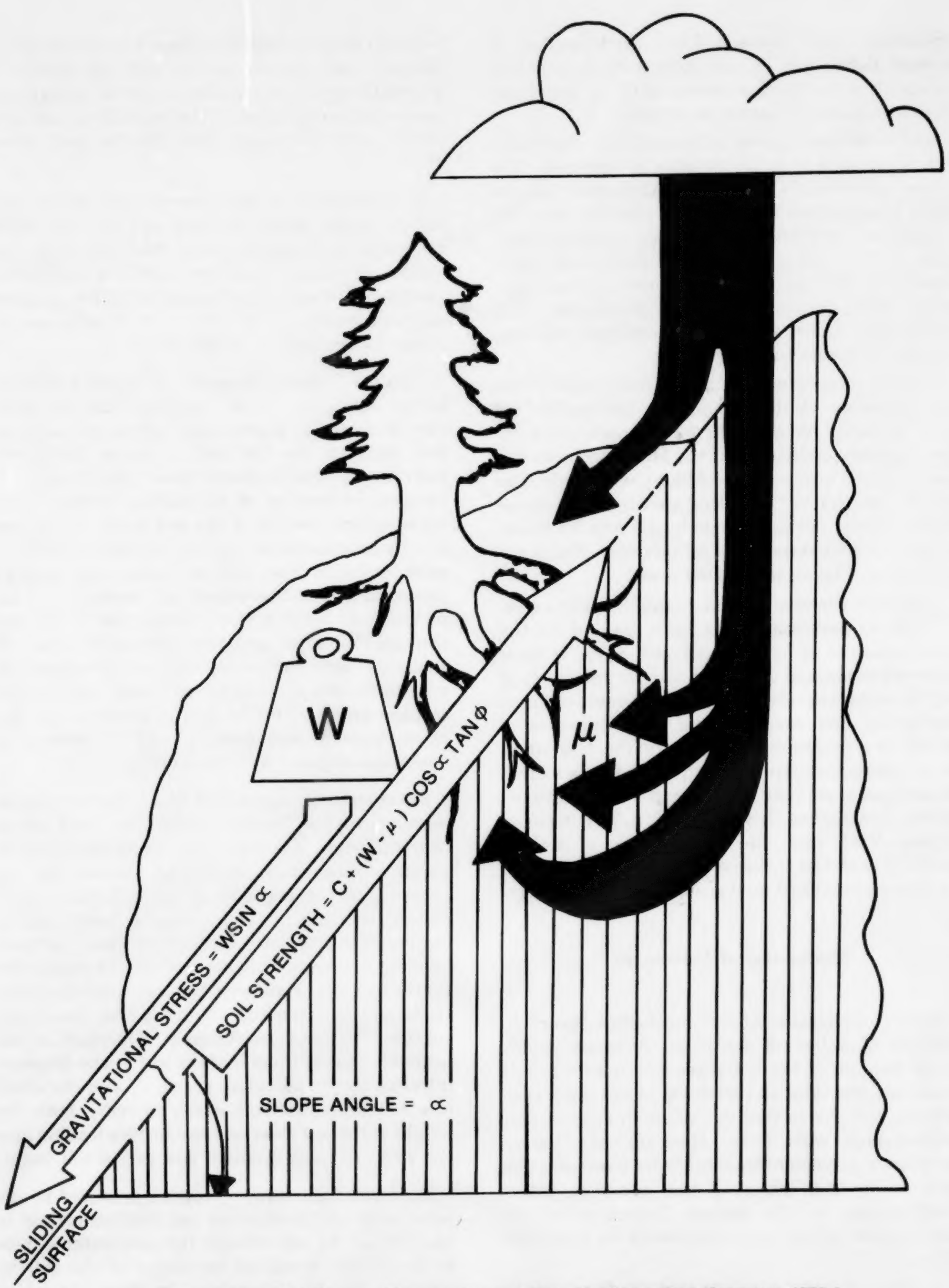

W
μ
GRAVITATIONAL STRESS = WSIN ∝
SOIL STRENGTH = C + (W - μ) COS∝ TAN φ
SLOPE ANGLE = ∝
SLIDING SURFACE

Figure V.7.—Simplified diagram of forces acting on a mass of soil on a slope (Swanston 1974a).

Controlling And Contributing Factors

Particle size distribution or "texture" (which governs cohesion), angle of internal friction, soil moisture content, and angle of sliding surface are the controlling factors in determining stability of a steepland soil. For example, shallow coarse-grained soils low in clay-size particles have little or no cohesion, and frictional resistance determines the strength of the soil mass. Frictional resistance is, in turn, strongly dependent on the angle of internal friction of the soil and pore water pressure. A low angle of internal friction relative to slope angle or high pore water pressure can reduce soil shear strength to negligible values.

Slope angle is a major indicator of the stability of low cohesion soils. Slopes at or above the angle of internal friction of the soil indicate a highly unstable natural state.

Soils of moderate to high clay content exhibit more complex behavior because resistance to sliding is determined by both cohesion and frictional resistance. These factors are controlled to a large extent by clay mineralogy and soil moisture. In a dry state, clayey soils have a high shear strength with the internal angle of friction quite high (>30°). Increasing water content mobilizes the clay through absorption of water onto the clay structure. The angle of internal friction is reduced by the addition of water to the clay lattices (in effect reducing "intragranular" friction) and may approach zero in saturated conditions. In addition, water between grains — interstitial water — may open the structure of the soil mass. This permits a "remolding" of the clay fraction, transforming it into a slurry, which then lubricates the remaining soil mass. Some clays are more susceptible to deformation than others, making clay mineralogy an important consideration in areas characterized by quasi-viscous flow deformation of "creep." Swelling clays of the smectite group (montmorillenite) are particularly unstable because of their tendency to absorb large quantities of water and to experience alternate expansion and contraction during periods of wetting and drying which may result in progressive failure of a slope. Thus, clay-rich soils have a high potential for failure given excess soil moisture content. Under these conditions, failures are not directly dependent on sliding surface gradient as in cohesionless soils, but may develop on slopes with gradients as low as 2° or 3°.

Parent material type has a major effect on the particle size distribution, depth of weathering, and relative cohesiveness of a steepland soil. It frequently can be used as an indicator of relative stability or potential stability problems. In humid regions where chemical weathering predominates, transformation of easily weathered primary minerals to clays and clay-size particles may be extensive. Siltstones, clay stones, shales, nonsiliceous sandstones, pyroclastics, and serpentine-rich rocks are the most easily altered and are prime candidates for soil mass movement of the creep and slump-earthflow types. Conversely, in arid or semiarid regions, slopes underlain by these rocks may remain stable for many years due to slow chemical weathering processes and lack of enough soil moisture to mobilize existing clay minerals. On steep lands underlain by resistant rocks, especially where mechanical weathering prevails, soils are usually coarse and low in clay-size particles. Such areas are more likely to develop soil mass movements of the debris avalanche-debris flow type.

Parent material structure is a critical factor in stability of many shallow soils. Highly jointed bedrock slopes with principal joint planes parallel to the slope provide little mechanical support to the slope and create avenues for concentrated subsurface flow and active pore water pressure development, as well as ready-made zones of weakness and potential failure surfaces for the overlying material. Sedimentary rocks with bedding planes parallel to the slope, function in essentially the same way, with the uppermost bedding plane forming an impermeable boundary to subsurface water movement, a layer restricting the penetration and development of tree roots, and a potential failure surface.

Vegetation cover generally helps control the amount of water reaching the soil and the amount held as stored water against gravity, largely through a combination of interception and evapotranspiration. The direct effect of interception on the soil water budget is probably not large, especially in areas of high total rainfall or during large storms, when most soil mass movements occur. Small storms, where interception is effective, probably have little influence on total soil water available for activating mass movements.

In areas of low rainfall, the effect of evapotranspiration is much more pronounced, but it is particularly dependent on region and rainfall. In areas characterized by warm, dry summers, evapotranspiration significantly reduces the degree of saturation resulting from the first storms of the fall recharge period. This effect diminishes as soil water deficit is satisfied. Once the soil is recharged, the effects of previous evapotranspirational losses become negligible. Conversely, in areas of continuous high rainfall or those with an arid or semiarid climate, evapotranspirational effects are probably negligible. Depth of evapotranspirational withdrawals is important also. Deep withdrawals may require substantial recharge to satisfy the soil water deficit, delaying or reducing the possibility of saturated soil conditions necessary for major slide-producing events. Shallow soils, however, recharge rapidly, possibly becoming saturated and most unstable during the first major storm.

Root systems of trees and other vegetation may increase shear strength in unstable soils by anchoring through the soil mass into fractures in bedrock, providing continuous long fiberous binders within the soil mass, and tying the slope together across zones of weakness or instability.

In shallow soils, all three effects may be important. In deep soils, the anchoring effect of roots becomes negligible, but the other parameters will remain important. In some extremely steep areas in western North America, root anchoring may be the dominant factor in maintaining slope equilibrium of an otherwise unstable area (Swanston and Swanson 1976).

Snow cover increases soil unit weight by surface loading and affects delivery of water to the soil by retaining rainfall and delaying release of much water. Delayed release of melt water, coupled with unusually heavy storms during a midwinter or early spring warming trend, has been identified as the principal initiating factor in recent major landslide activity on forest lands in central Washington (Klock and Helvey 1976).

CHARACTERIZING UNSTABLE SLOPES IN FORESTED WATERSHEDS

The following guidelines are designed to help delineate the hazards of unstable slopes on forested lands.

There are six environmental qualities that should be carefully considered when judging stability of natural slopes in terms of surface erosion and soil mass movement. They are:

A. landform features
B. soil characteristics
C. bedrock lithology and structure
D. vegetative cover
E. hydrologic characteristics of site
F. climate

Each of these qualities encompasses a group of factors which control stability conditions on the slope and determine or identify the type of processes and movements which are most likely to occur.

Key factors identifying potentially unstable slopes on any mountainous terrain include slope gradient (a landform quality) and concentration of precipitation (both intensity and duration). Soil properties, including soil depth and such diagnostic characteristics as texture, permeability, angle of internal friction, and cohesion determine the types of processes that will dominate and, to some degree, determine the stable slope gradient within a particular soil type. Bedrock structure, especially attitude of beds and degree of fracturing or jointing, are important contributing factors controlling local stability conditions. Many of these factors are identifiable on the ground or in readily available support documentation (climatological records, etc.).

The following outline discusses the six environmental qualities important for judging stability of natural slopes and the key factors associated with each.

A. Landform features

1. **Landforms on which subject area occurs.** — A qualitative indicator of potentially unstable landform types. Obtainable from air photos and topographic maps. For example, alpine glaciated terrain characteristically exhibits U-shaped valleys with extensive areas of very steep slope. Fracturing parallel to the slope is common, and soils, either of colluvial or glacial origin, are usually shallow and cohesionless. The underlying impermeable surface may be either bedrock or compact glacial till. Such terrain is frequently subject to debris avalanche-debris flow processes.

   Areas formed by continental glaciation commonly exhibit rolling terrain consisting of low hills and ridges composed of bedrock, glacial till, and stratified drift separated by areas of ground moraine and glacial outwash. Glaciolacustrine deposits may be present locally, consisting of thick deposits of silt and clay which may be particularly subject to slump-earthflow processes if disturbed.

Fluvially formed landscapes underlain by bedded sedimentary and meta-sedimentary rocks may have slope steepness controlled by jointing, fracturing, and faulting; by orientation of bedding; and by differential resistance of alternating rock layers. Debris avalanche-debris flow failures frequently occur in shallow colluvial soils along these structurally controlled surfaces. Slump-earthflow failures may occur in clay-rich or deeply weathered units, in deeply weathered soils and colluvial debris on the lower slopes, and in valley fills adjacent to active stream channels.

Volcanic terrain consisting of units of easily weathered volcaniclastic rocks and hard, resistant flow rock commonly exhibit slump-earthflow failures in deeply weathered volcaniclastic materials. Such failures usually occur just below a capping flow or just above an underlying flow due to concentration of ground water. Debris avalanche-debris flow failures are common in shallow residual or colluvial soils developed on the resistant flow rock units.

Because of the large variability in landform processes and the modifying influence of climatic conditions on weathering rates and products, geologists with some knowledge of the area should be consulted.

2. **Slope configuration.** — Shape of the slope in the area of consideration. A qualitative indicator of location and extent of most highly unstable areas on a slope. Obtainable from air photos and topographic maps. On both concave and convex slopes, usually the steepest portions have the greatest stability hazard. Convex slopes may have oversteep gradients in lower portions of the slope. Concave slopes have oversteep gradients in their upper elevations.

3. **Slope gradient.** — A key factor controlling soil stability in steep mountain watersheds. Slope gradient may be quantified on the ground or from topographic maps. It determines effectiveness of gravity acting to move a soil mass downslope. For aebris avalanche-debris flow failures, this is a major indicator of the natural soil mass movement hazard. For slump-earthflow failures, this is not as important since, given the right conditions of soil moisture content, soil texture, and clay mineral content, failures can occur on slope gradients as low as 2° or 3°. Slope gradient also has a major effect on subsurface water flow in terms of drainage rate and subsequent susceptibility to temporary water table buildup during high intensity storms.

B. Soil Characteristics

1. **Present soil mass movement type and rate.** — Obtainable from air photos and field checks. This is a qualitative indicator of size and location of potential stability problems, type of recent landsliding, and kinds of soil mass movement processes operative on the slope. These, in turn, suggest probable soil depth and certain dominant soil characteristics. For example, debris avalanches-debris flows most frequently develop in shallow, coarse-grained soils which have a low clay content and low internal cohesion. Soil creep, massive slumping, and large-scale earthflows usually develop in deep, cohesive soils high in clay content or in deeply weathered pelitic sediments, serpentinite, and volcanic ash and breccia.

2. **Parent material.** — A qualitative indicator of probable shape of soil particles, bulk density (or weight), degree of cohesion or clay mineral content, soil depth, permeability, and presence or absence of impermeable layers in the soil. These, in turn, suggest types of soil mass movement processes operative within an area. This information is obtainable from existing geologic and soil survey maps, by air photo interpretation, and by field check.

   Soils developed from colluvial or residual materials and some tills and pumice soils commonly possess little or no cohesion. Failures in such soils are usually of the debris avalanche-debris flow type.

   Soils developed from weathered fine grained sedimentary rocks (mudstones, claystones, nonsiliceous sandstones, shales), volcaniclastics, and glacio-lacustrine clays and silts possess a high degree of cohesion and characteristically develop failures of the slump-earthflow type.

   The mica content also has a major influence on soil strength. Ten to twenty percent mica will produce results similar to high clay content.

3. **Occurrence of compacted, cemented, or impermeable layer.** — A qualitative indicator of the depth of potentially unstable soil and probable principal planes of failure

on the slope. This information is obtainable from borings, soil pits, and inspection of slope failure scars in the field.

4. **Evidence of concentrated subsurface drainage (including evidence of seasonal saturation).** — A qualitative indicator of local zones of periodic high soil moisture content including saturation and potentially active pore water pressures during high rainfall periods. These identify potential areas of slope failure. This information is obtainable by air photo interpretation and ground observation. Diagnostic features include broad linear depressions perpendicular to slope contour, representing old landslide sites and areas of concentrated subsurface drainage, and damp areas on the slope, representing springs and areas of concentrated ground water movement.

5. **Diagnostic soil characteristics.** — Key factors in determining dominant types of soil mass movement process mechanics of motion and probable maximum and minimum stable slope gradients for a particular soil. This is identifiable through field testing, sampling, and laboratory analysis. Data on benchmark soils also may be obtained from soil surveys and engineering analyses for road construction in or adjacent to the proposed silvicultural activity.
   a. **Soil depth.** — Principal component of the weight of the soil mass and an important factor in determining soil strength and gravitational stress acting on an unstable soil.
   b. **Texture.** — (Particle size distribution) the relative proportions of sand (2.0 - 0.5 mm), silt (.05 - .002 mm), and clay (<.002 mm) in a soil. Texture, along with clay mineral content, are important factors in controlling cohesion, angle of internal friction, and hydraulic conductivity of an unstable soil.
   c. **Clay mineralogy.** — An indicator of sensitivity to deformation. Some clays are more susceptible to deformation than others, making clay mineralogy an important consideration in areas where creep occurs. "Swelling" clays of the smectite group (montmorillonite) are particularly unstable.
   d. **Angle of internal friction.** — An indicator of the internal frictional resistance of a soil caused by intergranular friction and interlocking of individual grains, an important factor in determining soil shear strength or resistance to gravitational stress. The tangent of the angle of internal friction times the weight of the soil constitute a mathematical expression of frictional resistance. For shallow, cohesionless soils, a slope gradient at or above the angle of internal friction is a good indicator of a highly unstable site.
   e. **Cohesion.** — The capacity of soil particles to stick or adhere together. This is a distinct soil property produced by cementation, capillary tension, and weak electrical bonding of organic colloids and clay particles. Cohesion is usually the direct result of high (20 percent or greater) clay particle content and is an important contributor to shear strength of a fine grained soil.

C. Bedrock Lithology and Structure

1. **Rock type.** — A qualitative indicator of overlying soil texture, clay mineral content, and relative cohesiveness. It provides a regional guide to probable areas of soil mass movement problems and dominant processes. For example, in the Cascades and Coast Range of Oregon and Washington, areas underlain by volcanic ash and breccias and silty sandstone are particularly susceptible to slump-earthflows. Where hard, resistant volcanic flow rock is present, shallow planar failures dominate. Slopes underlain by granites and diorites are also more susceptible to shallow planar failures, although where extensive chemical weathering has occurred, such rocks may exhibit slump-earthflow features. The slope stability characteristics of a particular rock type or formation largely depend on mineralogy, climate, and degree of weathering, and must be determined for each particular area.

2. **Degree of weathering.** — A qualitative indicator of soil depth and type of soil mass movement activities. In some rock types, it is also an indicator of degree of clay mineral formation.

3. **Attitude of beds.** — Quantifiable on the ground, from geologic maps, and occasionally

from air photos. This is an important contributing factor to unstable slopes, especially where attitude of bedding parallels or dips in the same direction as the slope. Under these conditions, the bedding planes form zones of weakness along which slope failures can occur due to high pore water pressures and decreases in frictional resistance. Conversely, bedding planes dipping into the slope frequently produce natural buttresses and increase slope stability. Care must be taken in assessing the stabilizing influence of horizontal or in-dipping bedding planes particularly where well-developed jointing is present (see no. 4).

4. **Degree of jointing and fracturing.** — Quantifiable on the ground and occasionally from geologic maps as dip and strike of faults, fractures, and joint systems. Joints in particular are important contributing factors to slope instability, especially on slopes underlain by igneous materials. Joints parallel to or dipping in the same direction as the slope, create local zones of weakness along which failures occur. Jointing also provides avenues for deep penetration of groundwater with subsequent active pore water pressure development along downslope dipping joint planes.

   Valleys developed along high angle faults in mountainous terrain may have exceptionally steep slopes. Deep penetration of ground water into uneroded fault and shear zones can result in extensive weathering and alteration of zone materials, resulting in generation of slump-earthflow failures. Such zones can also form barriers to ground water movement causing redirection and concentration of water into adjacent potentially unstable sites.

D. Vegetative Characteristics

1. **Root distribution and degree of root anchoring in the subsoil.** — An indicator of effectiveness of tree roots as a stabilizing factor in shallow steep slope soils. Quantifiable on the ground by observing the degree of penetration of roots through the soil and into a more resistant substratum and by measuring the biomass of the roots contained in a potentially unstable soil. High biomass of contained roots is an expression of the binding capacity or "reinforcing" effect of roots to the soil mass.
2. **Vegetation type and distribution.** — Cover density, vegetation type, and stand age are qualitative indicators of the history of soil mass movement on a site and soil and ground water conditions. This information is obtainable by air photo interpretation and ground checking.

E. Hydrologic Characteristics

1. **Hydraulic conductivity.** — A measure of water movement in and through soil material. This is quantifiable in the field and in the laboratory using pumping tests and permeameters. Low hydraulic conductivities mean rapid storm generated saturation and a high probability of active pore water pressure, which produces highly unstable conditions in steep slope soils.
2. **Pore water pressure.** — A measure of the pressure produced by the head of water in a saturated soil and transferred to the base of the soil through the pore water. This is quantifiable in the field through measurement of free water surface level in the soil. Pore water pressure is a key factor in failure of a steep slope soil, and operates primarily by reducing the weight component of soil shear strength.

F. Climate

1. **Precipitation occurrence and distribution.** — A key factor in predicting regional soil mass movement occurrences. Most soil mass movements are triggered by soil saturation and active pore water pressures produced by rainfall of high intensity and long duration. Isohyetal maps of rainfall occurrences and distribution, constructed from data obtainable from local monitoring stations or from the Weather Bureau, can be used to pinpoint local areas of high rainfall concentration. It is advisable to develop a simple relationship between rainfall intensity and pore water pressure development for a particular soil type or area of interest so that magnitude and return period of damaging storms can be identified. This can be done simply by locating a rain gage at the site or using nearby rainfall data and correlating this with piezometric data obtained from open-ended tubes installed to the probable depths of failure at the site. Each storm should be monitored.

THE PROCEDURE

ESTIMATING SOIL MASS MOVEMENT HAZARD AND SEDIMENT DELIVERED TO CHANNELS

This section delineates a procedure to be used on potentially unstable areas to analyze the hazard of soil mass movement associated with silvicultural activities and to determine the potential volume and delivery of inorganic material to the closest drainageway. This is a broad level analysis designed to determine where specific controls or management treatment variations are required because of possible water quality changes resulting from soil mass movement. This procedure will not substitute for site specific analysis of road design, maintenance, and rehabilitation as may be required under current management procedures.

To assess soil mass movement hazards that might deliver inorganic material to a stream course, a basic qualitative evaluation is undertaken based on the following information:

1. A delineation of hazard areas and dominant soil mass movement types using aerial photo and topographic map interpretation with minimum ground reconnaissance.
2. An estimate of the likelihood of failure or "sensitivity" of an area caused by both natural and man-induced events, using subjective analysis of controlling and contributing factors within defined hazard areas.
3. An estimate of the volume of material released by soil mass movements during storm events with a 10-year return interval or less.
4. An estimate of the volume of sediment released by soil mass movements which actually reach a water course based on slope position, gradient, and shape and type of movement.

Although soil mass movements are too infrequent for effective direct annual evaluation, delivery volumes can be expressed on an average annual basis for purposes of comparison between pre- and post-silvicultural activity conditions.

A broad delineation of potentially unstable terrain by slope characteristics and soil mass movement types is an essential part of the hazard analysis. A detailed flow chart (fig. V.8) shows the sequence of analysis once the delineation of unstable terrain is accomplished.

The limits placed on variable ranges for high, medium and low hazard indices are approximations based on the collective experience of practicing professionals. The weighted values for hazard indices are guides only, and they were determined from consultation with practicing professionals as well as a limited analysis of several unstable areas in Colorado and western Oregon. However, they do reflect the relative importance of the individual factors and their effects on likelihood of failure by the major soil mass movement types. These weightings and the ranges of hazard index should be adjusted to reflect the conditions prevalent within a given area.

PROCEDURAL DESCRIPTION

The following information describes each step of the procedural flow chart, fig V.8. Data from the Horse Creek example are used to illustrate the following procedure. This complete example is presented in "Chapter VIII: Procedural Example."

BROAD DELINEATION OF POTENTIALLY UNSTABLE AREAS

Guidelines have been presented that provide a qualitative characterization of unstable or potentially unstable slopes on forested lands. Using these guidelines, evaluate the area of the proposed silvicultural activity to ascertain the stability of the site.

IDENTIFY AND MAP AREAS BY SOIL MASS MOVEMENT TYPE

If the area is generally unstable or potentially unstable, delineate the hazard areas and dominant soil mass movement types (debris avalanches-debris flows and slump-earthflows) using aerial photos and topographic map interpretation. Potentially unstable areas are those that may become unstable due to the proposed silvicultural activity. Unstable areas are those that have or presently are undergoing a soil mass movement.

CHARACTERIZE SOIL MASS MOVEMENT TYPE

Soil mass movements have been classified into two major types: debris avalanches-debris flows and slump-earthflows. Several site parameters and management activities can be used to evaluate the possibility of soil mass movement. Although both movement types have similar factors that can be used to evaluate the hazard of a failure, the relative importance of these factors may be different between the two movement types. In addition, each kind of soil mass movement has some site or management activity parameters that are specific for that movement. Therefore, to evaluate the hazard of a soil mass movement, each type must be evaluated separately using the factors that have been found to be significant in characterizing that particular kind of failure.

DEBRIS AVALANCHE-DEBRIS FLOW

Areas prone to debris avalanches-debris flows are typified by shallow, noncohesive soils on steep slopes where subsurface water may be concentrated by subtle topography on bedrock or glacial till surfaces.

NATURAL HAZARD SITE CHARACTERISTICS

For debris avalanches-debris flows, the following site characteristics have been found to be critical in evaluating the potential hazard of a natural soil mass movement: slope gradient, soil depth, subsurface drainage characteristics, soil texture, bedding structure and orientation, surface slope configuration, and precipitation input. This information can be obtained from geologic and soils maps, pertinent literature, field knowledge of local experts, etc. The relative importance of each site characteristic is indicated in table V.5 and worksheet V.1 by the weighting value assigned.

MANAGEMENT INDUCED HAZARD CHARACTERISTICS

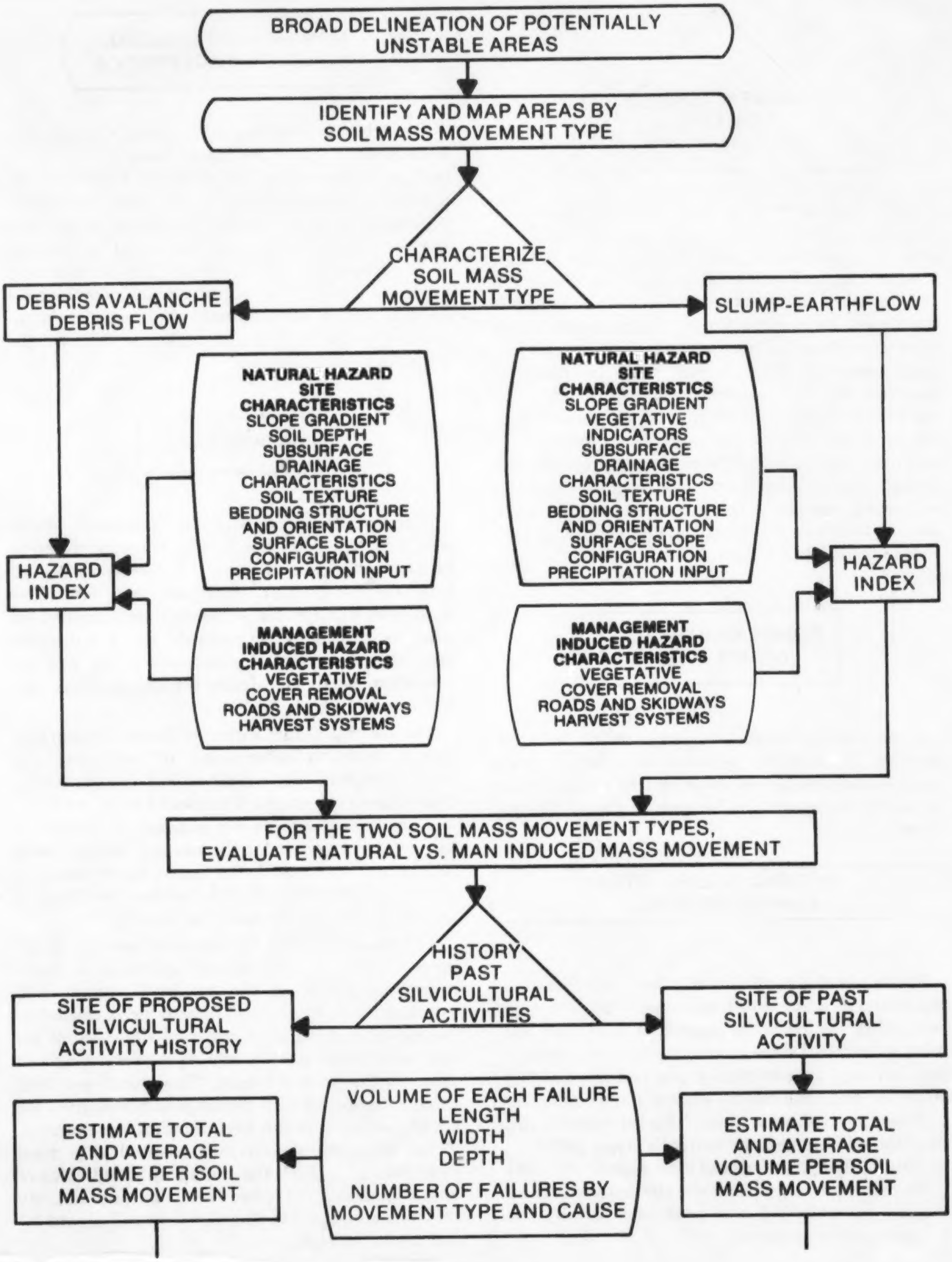
For debris avalanches-debris flows, the following management activities have been found to be critical in evaluating the potential hazard for initiation or acceleration of a soil mass movement: vegetative cover removal, roads and skidways, and harvest systems. This information can be obtained from past records of silvicultural activities or from proposed silvicultural activity plans. The relative importance of each management activity is indicated in table V.6 and worksheet V.2 by the weighting value assigned.

HAZARD INDEX

The hazard index analysis procedure places weighted values on the factors affecting different types of soil mass movement. A three-part hazard index is used: high, medium, and low. The numerical ratings are subjective and depend on what is considered acceptable for a particular silvicultural activity. Assumptions 1 and 2 in the procedure detail and define a high, medium, and low hazard.

The natural hazard index for debris avalanches-debris flows is determined by summing the weighted values from worksheet V.1 and comparing this value to the ranges of values for high, medium, and low hazard indices. For example, if the sum of the weighted values for the natural hazard index (worksheet V.1) was 31, the hazard index would be medium. The value 31 falls within the range of values (21-44) for the medium hazard.

The relative hazard for debris avalanches-debris flows caused by silvicultural activities is determined by summing the weighted values from worksheet V.2. The overall hazard index caused by natural plus existing or proposed silvicultural activities is determined by adding the total weighted value for the natural hazard. This overall weighted value is compared with the range of values given for a high, medium, or low hazard index. For example, if the silvicultural activities resulted in a total weighted value of 31, the overall weighted value of both the natural (31) plus the silvicultural activity (31) would be equal to 62 and the overall hazard index would be high.


BROAD DELINEATION OF POTENTIALLY UNSTABLE AREAS
IDENTIFY AND MAP AREAS BY SOIL MASS MOVEMENT TYPE
CHARACTERIZE SOIL MASS MOVEMENT TYPE
DEBRIS AVALANCHE DEBRIS FLOW
SLUMP-EARTHFLOW
NATURAL HAZARD SITE CHARACTERISTICS
SLOPE GRADIENT
SOIL DEPTH
SUBSURFACE DRAINAGE CHARACTERISTICS
SOIL TEXTURE
BEDDING STRUCTURE AND ORIENTATION
SURFACE SLOPE CONFIGURATION
PRECIPITATION INPUT
NATURAL HAZARD SITE CHARACTERISTICS
SLOPE GRADIENT
VEGETATIVE INDICATORS
SUBSURFACE DRAINAGE CHARACTERISTICS
SOIL TEXTURE
BEDDING STRUCTURE AND ORIENTATION
SURFACE SLOPE CONFIGURATION
PRECIPITATION INPUT
HAZARD INDEX
HAZARD INDEX
MANAGEMENT INDUCED HAZARD CHARACTERISTICS
VEGETATIVE COVER REMOVAL
ROADS AND SKIDWAYS
HARVEST SYSTEMS
MANAGEMENT INDUCED HAZARD CHARACTERISTICS
VEGETATIVE COVER REMOVAL
ROADS AND SKIDWAYS
HARVEST SYSTEMS
FOR THE TWO SOIL MASS MOVEMENT TYPES, EVALUATE NATURAL VS. MAN INDUCED MASS MOVEMENT
HISTORY PAST SILVICULTURAL ACTIVITIES
SITE OF PROPOSED SILVICULTURAL ACTIVITY HISTORY
SITE OF PAST SILVICULTURAL ACTIVITY
ESTIMATE TOTAL AND AVERAGE VOLUME PER SOIL MASS MOVEMENT
VOLUME OF EACH FAILURE
LENGTH
WIDTH
DEPTH
NUMBER OF FAILURES BY MOVEMENT TYPE AND CAUSE
ESTIMATE TOTAL AND AVERAGE VOLUME PER SOIL MASS MOVEMENT

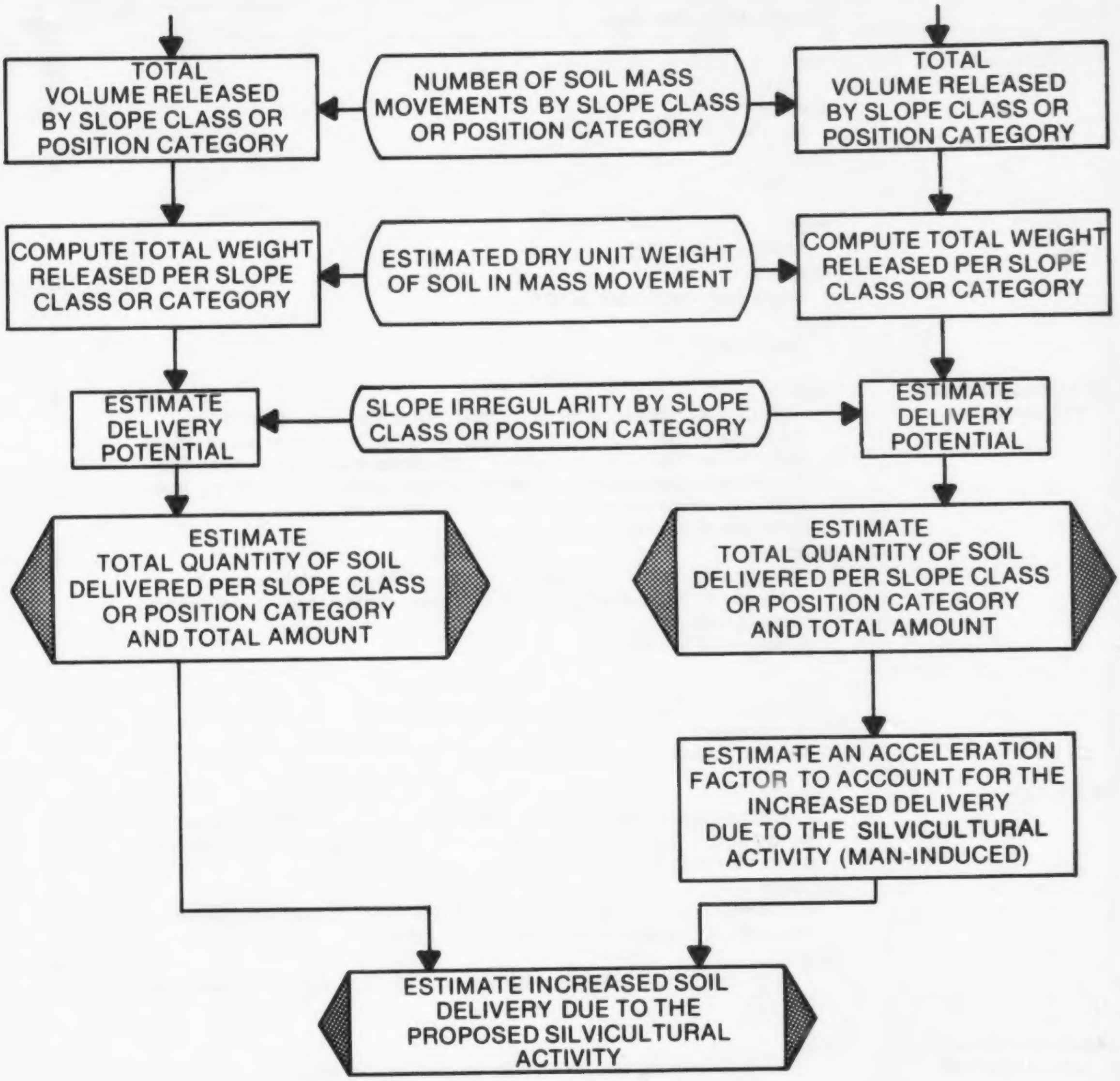

TOTAL VOLUME RELEASED BY SLOPE CLASS OR POSITION CATEGORY
NUMBER OF SOIL MASS MOVEMENTS BY SLOPE CLASS OR POSITION CATEGORY
TOTAL VOLUME RELEASED BY SLOPE CLASS OR POSITION CATEGORY
COMPUTE TOTAL WEIGHT RELEASED PER SLOPE CLASS OR CATEGORY
ESTIMATED DRY UNIT WEIGHT OF SOIL IN MASS MOVEMENT
COMPUTE TOTAL WEIGHT RELEASED PER SLOPE CLASS OR CATEGORY
ESTIMATE DELIVERY POTENTIAL
SLOPE IRREGULARITY BY SLOPE CLASS OR POSITION CATEGORY
ESTIMATE DELIVERY POTENTIAL
ESTIMATE TOTAL QUANTITY OF SOIL DELIVERED PER SLOPE CLASS OR POSITION CATEGORY AND TOTAL AMOUNT
ESTIMATE TOTAL QUANTITY OF SOIL DELIVERED PER SLOPE CLASS OR POSITION CATEGORY AND TOTAL AMOUNT
ESTIMATE AN ACCELERATION FACTOR TO ACCOUNT FOR THE INCREASED DELIVERY DUE TO THE SILVICULTURAL ACTIVITY (MAN-INDUCED)
ESTIMATE INCREASED SOIL DELIVERY DUE TO THE PROPOSED SILVICULTURAL ACTIVITY

Figure V.8.—Detailed flow chart of the soil mass movement procedure.

Table V.5.—Weighting factors for determination of natural hazard of debris avalanche-debris flow failures

Factor	Hazard index and range	Weight
Slope gradient	High >34°	30
	Medium 29° -34°	15
	Low <29°	5
Soil depth	High Shallow soils, <5 ft	3
	Medium Moderately deep soils, 5-10 ft	2
	Low Deep soils, >10 ft	1
Subsurface drainage characteristics	High High density, closely spaced incipient drainage depressions Presence of bedrock or impervious material at shallow depth which restricts vertical water movement and concentrates subsurface flow Presence of permeable low density zones above the restricting layer indicative of saturated flow parallel to the slope Evidence of springs on the slope	3
	Medium Presence of incipient drainage depressions, but widely spaced Presence of impervious material at shallow depths, but no low density zones present Springs are absent	2
	Low Incipient drainage depressions rare to absent No shallow restricting layers present No indications of near-surface flow	1
Soil texture	High Unconsolidated, non-cohesive soils and colluvial debris including sands and gravels, rock fragments, weathered granites, pumice and noncompacted glacial tills with low silt content (<10%) and no clay	3
	Medium Unconsolidated, non-cohesive soils and colluvial debris with moderate silt content (10-20%) and minor clay (<10%)	2
	Low Fine grained, cohesive soils with greater than 20% clay sized particles or mica	0
Bedding structure and orientation	High Extensive jointing and fracturing parallel to the slope Bedding planes parallel to the slope Faulting or shearing parallel to the slope (the stability influence of bedding planes horizontal or dipping into the slope is offset by extensive parallel jointing and fracturing)	3
	Medium Bedding planes are horizontal or dipping into the slope with minor jointing at angles less than the natural slope gradient Minor surface fracturing — no faulting or shearing evident	2
	Low Bedding planes are horizontal or dipping into the slope Jointing and fracturing is minor — no faulting or shearing evident	1

Table V.5.—Weighting factors for determination of natural hazard of debris avalanche-debris flow failures — continued

Factor	Hazard index and range	Weight
Surface slope configuration	High Smooth, continuous slopes unbroken by benches or rock outcrops Intermittent steep channels occur frequently with lateral spacing of 500 ft (152 m) or less Perennial channels frequently deeply incised with steep walls of rock or colluvial debris Numerous breaks in canopy due to blow-downs — frequent linear or tear-drop shaped even-age stands beginning at small scarps or spoon-shaped depressions indicative of old debris avalanche-debris flow activity	3
	Medium Smooth, continuous slopes broken by occasional benches and rock outcrops Intermittent, steep gradient channels occur less frequently with a lateral spacing of 500-800 ft (152-244 m) Infrequent evidence of blow-down or past landslide activity	2
	Low Slope broken by rock benches and outcrops intermittent, steep gradient channels spaced 900 ft (275 m) or more apart	1
Precipitation input	High Area characterized by rainfall greater than 80 in/yr (203 cm/yr) distributed throughout the year or greater than 40 in/yr (102 cm/yr) distributed over a clearly definable rainy season Locale is subjected to frequent high intensity storms capable of generating saturated soil conditions on the slope leading to active pore-water pressure development and high stream flow — area has a high potential for mid-winter or early spring rainfall-on-snowpack events Storm intensities may exceed 6 in/24 hr at 10 yr recurrence intervals or less	12
	Medium Area characterized by moderate rainfall of 20 to 40 in/yr (51 to 102 cm/yr) Storms of moderate intensity and duration are common High intensity storms are infrequent, but do occasionally occur Moderate snowpack, but rain-on-snow events very rare Storm intensities may exceed 6 in/24 hr (15 cm/24 hr) at recurrence intervals greater than 10 yrs.	5
	Low Rainfall in area is low (less than 20 in/yr) Storms infrequent and of low intensity Stored water content in snowpack, when present, is low and only rarely subject to rapid melting	3

WORKSHEET V.1

Debris avalanche-debris flow natural factor evaluation form

Index	Slope gradient	Soil depth	Subsurface drainage characteristics	Soil texture	Bedding structure and orientation	Slope configuration	Precipitation input
High	30	3	[✓ 3]	3	3	3	12
Medium	[✓ 15]	[✓ 2]	2	[✓ 2]	[✓ 2]	[✓ 2]	[✓ 5]
Low	5	1	1	0	1	1	3

Factor summation table

Gross hazard index	Factor range	Natural
High	Greater than 44	
Medium	21 - 44	31
Low	Less than 21	

Table V.6.—Weighting factors for determination of management-induced hazard of debris avalanche-debris flow failures

Factor	Hazard index and range	Weight
Vegetation cover removal	High Total removal of cover — large clearcuts with openings continuous downslope — such removal is sufficient to increase soil moisture levels and reduce strength Broadcast burning of slash	8
	Medium Cover partially removed with slope sections >34° left undisturbed — clearcuts in small patches or strips less than 20 ac (8 ha) and discontinuous on slopes	5
	Low Cover density altered through partial cutting — no clearcutting — no broadcast burning of sites with >34° slope	2
Roads and skidways	High High density (>15% of area in roads) on potentially unstable slopes (>28°) — cut and fill construction Roads and skidways located on steep, unstable portions of the slope (>34°) Uncontrolled fills with poor compaction produced by side-casting over organic debris Inadequate cross drainage (poor location; improper spacing and maintenance, size too small for 10 yr storm flow) Lack of fill slope protection of drainage outlets Concentrations of drainage water directed into identifiable unstable areas	20
	Medium Mixed road types, both fully benched and cut-and-fill (balanced) — moderate road density (8-15% of area) Areas with slopes >34° or with identifiable landslide activity have been avoided or fully benched On potentially unstable slopes >29° skidways and cut-and-fill type construction are limited Ridgetop roads have large fills in saddles Fills, where present, are constructed by sidecasting over organic debris with little controlled compaction Roads generally have adequate cross drains for normal runoff conditions (number and location) but are undersized for the 10 yr storm flow Fill slopes below culvert outfalls protected by rip-rap dissipation structures at potentially unstable sites Major concentrations of water into identifiable unstable areas avoided	8
	Low Very few roads on slopes above 28° — low road density (less than 8% of area) with roads on potentially unstable terrain (slopes between 29° and 34°) predominantly of full bench type — most road locations or construction limited to ridgetops with minimum fills in saddles and lower slopes — adequate cross drains with major water courses bridged and culverts designed for 10 yr storm flow or larger	2
Harvest systems	High Operation of tractor yarding, jammer yarding and other ground lead systems on slopes >29° (53%)	3
	Medium No tractor logging — high lead with partial suspension on slopes >29° (53%)	2
	Low Helicopter and balloon yarding — full suspension of logs by any method — yarding by any method on slopes <29° (53%)	0

WORKSHEET V.2

Debris avalanche-debris flow management related factor evaluation form

Index	Vegetation cover removal	Roads and skidways	Harvest methods
High	[✓ 8]	[✓ 20]	[✓ 3]
Medium	5	8	2
Low	2	2	0

Factor summation table

Gross hazard index	Range	Natural + management
High	Greater than 44	31+31 = 62
Medium	21 - 44	
Low	Less than 21	

SLUMP-EARTHFLOW

Slump-earthflow prone areas are typified by deep, cohesive soils and clay-rich bedrock overlying hard, competent rock. Slump-earthflow soil mass movement also appears to be sensitive to long-term fluctuations.

NATURAL HAZARD SITE CHARACTERISTICS

For slump-earthflows, the following site characteristics have been found to be critical in evaluating the potential hazard of a natural soil mass movement: slope gradient, sub-surface drainage characteristics, soil texture, surface slope configuration, vegetative indicators, bedding structure and orientation, and precipitation input. This information can be obtained from soils maps, vegetative cover maps, pertinent literature, field knowledge of local experts, etc. The relative importance of each site characteristic is indicated in table V.7 and worksheet V.3 by the weighting value assigned.

MANAGEMENT INDUCED HAZARD CHARACTERISTICS

For slump-earthflows, the following management activities have been found to be critical in evaluating the potential hazard for initiation or acceleration of a soil mass movement: vegetative cover removal, roads and skidways, and harvest systems. This information can be obtained from past records of silvicultural activities or from proposed silvicultural activity plans. The relative importance of each management activity is indicated in table V.8 and worksheet V.4 by the weighting value assigned.

HAZARD INDEX

The hazard index analysis procedure places weighted values on the factors affecting different types of soil mass movement. A three-part hazard index is used: high, medium, and low. The numerical ratings are subjective and depend on what is considered acceptable for a particular silvicultural activity. Assumptions 1 and 2 in the procedure detail and define a high, medium, and low hazard.

The natural hazard index for slump-earthflows is determined by summing the weighted values from worksheet V.3 and comparing this value to the ranges of values for high, medium, and low hazard index. For example, if the sum of the weighted values for the natural hazard index (wksht. V.3) was 38, the hazard index would be medium. The value 38 falls within the range of values (22-44) for the medium hazard.

The relative hazard for slump-earthflows caused by silvicultural activities is determined by summing the weighted values from worksheet V.4. The overall hazard index resulting from natural plus existing or proposed silvicultural activities is determined by adding the total weighted value from silvicultural activities to the total weighted value for the natural hazard. This overall weighted value is compared with the range of values given for a high, medium, or low hazard index. For example, if the silvicultural activities resulted in a total weighted value of 8, the overall weighted value of both the natural (38) plus the silvicultural activity (8) would be equal to 46, and the overall hazard index would be high.

FOR THE TWO TYPES OF SOIL MASS MOVEMENTS, EVALUATE NATURAL VS. MAN-INDUCED MASS MOVEMENT

Determine the quantity of material delivered to a stream channel for each soil mass movement type and evaluate any man-induced increase in mass movement over that naturally occurring.

Table V.7.—Weighting factors for determination of natural hazard of slump-earthflow failures

Factor	Hazard index and range	Weight
Slope gradient	High greater than 30° (58%)	6
	Medium 15 - 30° (27%-58%)	4
	Low under 15° (27%)	2
Subsurface drainage characteristics	High Area exhibits abundant evidence of impaired groundwater movement resulting in local zones of saturation within the soil mass — short, irregular surface drainages which begin and end on the slope Impaired drainage, indicated at the surface by numerous sag ponds with standing water, springs and patches of wet ground Impaired drainage involves more than 20% of the area	6
	Medium Some indications of impaired drainage, but generally involving less than 10% of the area Active springs are uncommon, infrequent, or contain no standing water	4
	Low No evidence of impaired drainage	2
Soil texture	High Predominantly fine grained cohesive soils derived from weathered sedimentary rocks, volcanics, aeolian and alluvial silts and glaciolacustrine silts and clays Clay sized particle content generally greater than 20% Clay minerals predominantly of the smectite group (montmorillonite), exhibiting swelling characteristics upon wetting	15
	Medium Soils of variable texture including both fine and coarse grained components in layers and lenses The fine grained, cohesive component may contain a clay sized particle content greater than 20%, but clay minerals are predominantly of the illite and kaolinite groups, exhibiting lower sensitivity to changes in stress	10
	Low Soils of variable texture Some clayey soils present but widely dispersed in small layers or lenses	5
Slope configuration	High 40% or more of the area is characterized by hummocky topography consisting of rolling, bumpy ground, frequent benches and depressions locally enclosing sag ponds Tension cracks and headwall scarps indicating slumping are unvegetated and clearly visible Slopes are irregular and may be slightly concave in the upper 1/2 and convex in the lower 1/2 as a result of the downslope redistribution of soil materials Zones of active movement are abundant	5
	Medium 5% to 40% of the area is characterized by hummocky topography Occasional sag ponds occur, but slump depressions are generally dry Headwall scarps are revegetated and no open tension cracks are visible Active slump-earthflow features are absent	2

Table V.7.—Weighting factors for determination of natrual hazard of slump-earthflow — continued

Factor	Hazard index and range	Weight
	Low Less than 5% of the area is characterized by hummocky topography Old slump-earthflow features are absent or subdued by weathering and erosion No active slump earthflow features present, slopes are generally smooth and continuous from ridge to valley floor	1
Vegetative indicators	High Phreatophytic (wet site) vegetation widespread Tipped (jackstrawed) and split trees are common Pistol-butted trees occur in areas of obvious hummocky topography (note: pistol-butted trees should be used as indicators of active slump-earthflow activity only in the presence of other indicators — pistol-butting can also occur in areas of high snowfall and is often the result of snow creep and glide)	5
	Medium Phreatophytic vegetation limited to occasional moist areas on the open slope and within sag ponds Tipped trees absent	3
	Low Phreatophytic vegetation absent	0
Precipitation input	High Area characterized by high rainfall of greater than 80 in/yr (203 cm/yr) distributed throughout the year or greater than 40 in/yr (102 cm/yr) distributed over a clearly definable rainy season Locale is subjected to frequent high intensity, long duration storms capable of generating continuing saturated conditions within the soil mass leading to active pore water pressure development and mobilization of the clay fraction Area has a high potential for rain-on-snow events	18
	Medium Area characterized by moderate rainfall of 20 to 40 in/yr (51 cm/yr to 102 cm/yr) Storms of moderate intensity and duration are common Snowpack is moderate, but rain-on-snow events are rare	10
	Low Rainfall in the area is low (less than 20 in/yr) storms are infrequent and of low intensity and duration Stored water content in the snowpack, when present, is low throughout the winter with no mid-winter or early spring releases due to climatological events	2

WORKSHEET V.3

Slump-earthflow natural factor evaluation form

Index	Slope gradient	Subsurface drainage characteristics	Soil texture	Slope configuration	Vegetative indicators	Precipitation input
High	[✓ 6]	6	15	[✓ 5]	5	18
Medium	4	[✓ 4]	[✓ 10]	2	[✓ 3]	[✓ 10]
Low	2	2	5	1	0	2

Factor summation table

Gross hazard index	Range	Natural
High	Greater than 44	38
Medium	21 - 44	
Low	Less than 21	

Table V.8.—Weighting factors for determination of management induced hazard of slump-earthflow failures

Factor	Hazard index and range	Weight
Vegetation cover removal	High Total removal of cover or large clearcuts with openings continuous downslope — such removal would be sufficient to increase soil moisture levels and reduce root strength	3
	Medium Cover partially removed — clearcuts in small patches or strips less than 20 acres (8 ha) is size and discontinuous downslope	2
	Low Cover density altered through partial cutting, no clearcutting evident	1
Roads and skidways	High High density (>15% of area in roads) cut-and-fill type (balanced) construction Roads and skidways located or planned across identifiable unstable ground Roads crossing active or dormant slump-earthflow features Massive fills or spoil piles on slump benches Inadequate drainage creating concentrations of water at the surface with diversion of surface drainage into unstable areas	7
	Medium Mixed road types, both fully benched and cut-and-fill (balanced) — moderate road density (8-15% of area in roads), unstable areas features avoided Roads generally have adequate cross drains for normal runoff conditions but are undersized for 10 yr storm flows Diversions of concentrations of water into unstable sites avoided	4
	Low No roads present — if present, predominantly fully benched Road density less than 8% Most road location and construction on ridgetops or in alluvial valley floors Adequate cross drainage with dispersal rather than heavily concentrated surface flow	2
Harvest systems	High Operation of tractor yarding, jammer yarding or other ground lead systems causing excessive ground disturbance	3
	Medium High lead yarding with partial suspension and skyline with partial suspension No tractor yarding	2
	Low Helicopter and balloon yarding Full suspension of logs by any method	1

WORKSHEET V.4

Slump-earthflow management related factor evaluation form

Index	Vegetation cover removal	Roads and skidways	Harvest methods
High	[✓ 3]	7	[✓ 3]
Medium	2	4	2
Low	1	[✓ 2]	1

Factor summation table

Gross hazard index	Range	Natural + management
High	Greater than 44	38+8=46
Medium	21 - 44	
Low	Less than 21	

HISTORY OF PAST SILVICULTURAL ACTIVITIES

To estimate the man-induced increase in the amount of soil delivered to a stream channel caused by silvicultural activities, it is necessary to compare soil mass movement in an area that has not been subjected to silvicultural activities with soil mass movement in an area that has been subjected to silvicultural activities. It is essential that the area selected for its previous silvicultural activities be identical or very similar to the undisturbed area, not only in physical site conditions, but also in proposed silvicultural activities. The proposed site of the silvicultural activity may or may not have existing soil mass movement which could be measured and quantified. The other area should have a history, if possible, of soil mass movements from both natural and man-induced causes.

SITE OF PROPOSED SILVICULTURAL ACTIVITY

If the proposed silvicultural activity is to be conducted in a previously undisturbed area, the inherent natural instability of the site can be estimated based upon existing failures or upon failures occurring on a similarly undisturbed site.

SITE OF PAST SILVICULTURAL ACTIVITY

Select an area adjacent to the proposed site of the silvicultural activity, with similar site characteristics and a history of similar silvicultural activities. The inherent natural instability of the area can be estimated based upon existing failures. Failures caused or accelerated by the silvicultural activity can also be measured.

VOLUME OF EACH FAILURE AND NUMBER OF FAILURES BY MOVEMENT TYPE & CAUSE

The site is inventoried using aerial photos and possibly a limited field reconnaissance and a record is made of each soil mass movement (the length, width, and depth), (figs. V.9 and V.10). The cause of each mass movement, either natural or in the case of areas that have been subjected to past silvicultural activity, man-induced, and the type of mass movement are noted. The number of soil mass movements by cause (natural vs. man-induced) and type is computed.

ESTIMATE TOTAL & AVERAGE VOLUME PER SOIL MASS MOVEMENT

The volume of individual soil mass movements (V) is computed on worksheet V.5 by multiplying the length (L), width (W), and depth (D) to obtain cubic feet of soil moved. The total soil mass movement by type (debris avalanche-debris flow and slump-earthflow) is computed by summing the volumes of the individual failures (wksht. V.5). These values are summed and recorded on worksheet V.6, step 1. The total number (N) of failures by soil mass movement type is recorded on worksheet V.6, step 2. The average volume per soil mass movement (V_A) by movement type is computed by dividing the total volume (V_t) by the number of failures (N) or $V_A = V_t/N$ and is recorded on worksheet V.6, step 3. For example, if the total volume (V_t) for debris avalanches-debris flows was 17,205 ft^3 (487 m^3) and the number of debris avalanche-debris flow (N) was 5, the average volume per debris avalanche-debris flow (V_A) would equal 3,441 ft^3 (162 m^3) or $V_A = 17{,}205\ \text{ft}^3/5 = 3{,}441\ \text{ft}^3$.

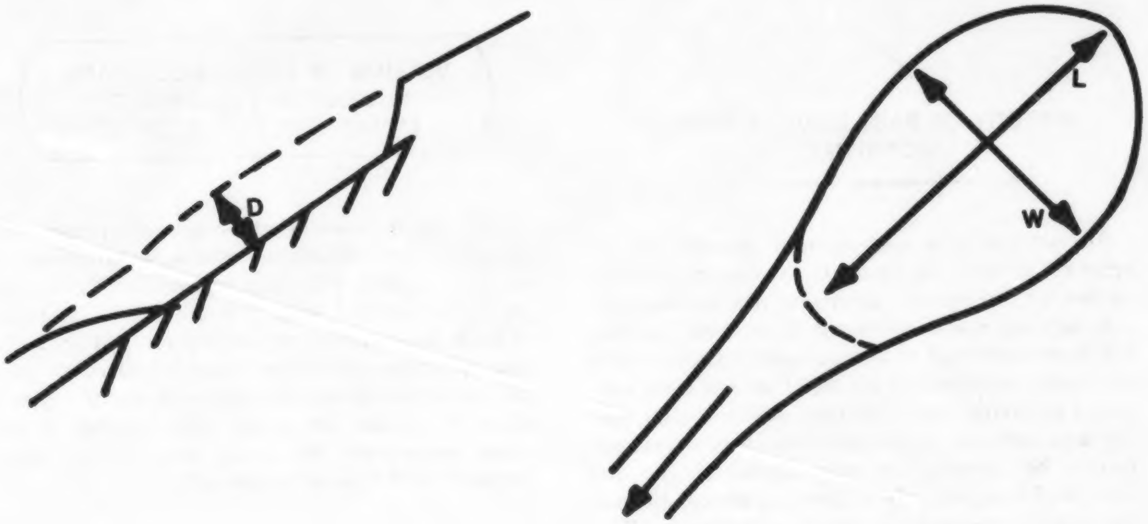


Figure V.9.—Dimensions of debris avalanche-debris flow failures for determining potential volumes. W = width; L = length; D = depth.

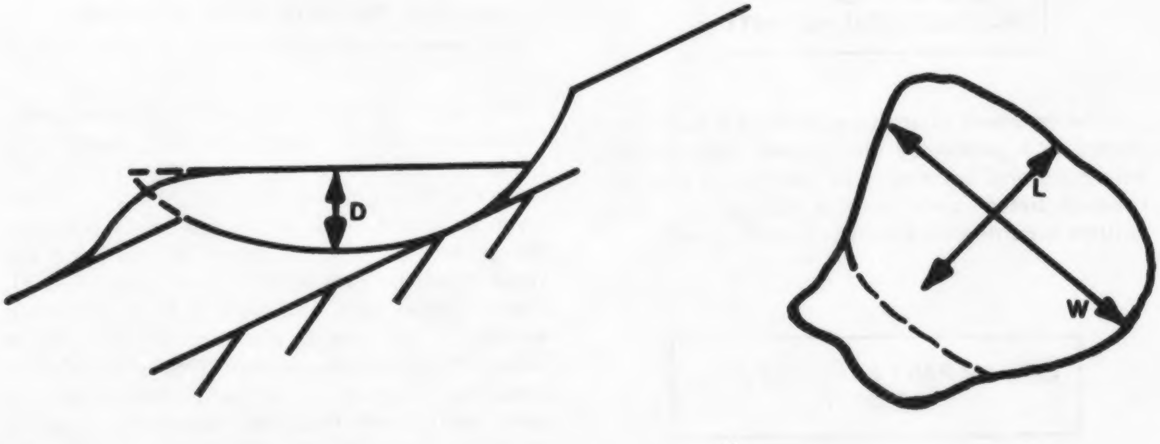


Figure V.10—Dimensions of slump-earthflow failures for determining potential volumes. W = width; L = length; D = depth.

WORKSHEET V.5

Estimation of volume per failure

	Debris avalanche-debris flow						Slump earthflow					
Slide Number	Natural	Man-induced	Length (ft)	Width (ft)	Depth (ft)	Volume (ft^3)	Natural	Man-induced	Length (ft)	Width (ft)	Depth (ft)	Volume (ft^3)
Horse	Creek											
1	X		84	28	1.5	3,528						
Mule	Creek											
1		X	80	24	1.5	3,880						
2		X	129	26	1.5	5,031						
3		X	121	17	1.5	3,086						
4		X	113	18	1.5	3,041						
5		X	95	23	1.5	3,278						
1	X		115	19	1.5	3,280						

WORKSHEET V.6

Estimation of soil mass movement delivered to the stream channel

(1) Watershed name Mule Creek

Factor (2)		Soil mass movement type			
		Debris avalanche-Debris flow		Slump flow	
		Natural (3)	Man-induced (4)	Natural (5)	Man-induced (6)
1 Total volume (V_t) in ft^3		3280	17205	—	—
2 Total number of failures (N)		1	5	—	—
3 Average volume per failure (VA)(ft^3)		3280	3441		
4 Number of failures per slope class	a	1	2		
	b	—	2		
	c	—	1		
5 Number of failures per slope position category	a'			—	—
	b'			—	—
	c'			—	—
	d'			—	—
6 Total volume per slope class or position category (V) in ft^3 $V = V_A \times N$	V_a $V_{a'}$	3280	6882	—	—
	V_b $V_{b'}$	—	6882	—	—
	V_c $V_{c'}$	—	3441	—	—
	$V_{d'}$			—	—
7 Unit weight of dry soil material (γ_d) (lb/ft^3)		99	99	—	—

WORKSHEET V.6--continued

8 Total weight per slope class or position category (W) in tons $W = \frac{V \times \gamma_d}{2{,}000}$	W_a $W_{a'}$	163	341	—	—
	W_b $W_{b'}$	—	341	—	—
	W_c $W_{c'}$	—	171	—	—
	$W_{d'}$			—	—
9 Slope irregularity--smooth or irregular		smooth	smooth	—	—
10 Delivery potential (D) as a decimal percent for slope class or position category	D_a $D_{a'}$	0.62	0.50	—	—
	D_b $D_{b'}$	—	0.30	—	—
	D_c $D_{c'}$	—	0.15	—	—
	$D_{d'}$			—	—
11 Total weight of soil delivered per slope class or position category (S) in tons $S = W \times D$	S_a $S_{a'}$	101	171	—	—
	S_b $S_{b'}$	—	102	—	—
	S_c $S_{c'}$	—	26	—	—
	$S_{d'}$			—	—
12 Total quantity of sediment delivered to the stream channel in tons		101 (400)	299	—	—
13 Acceleration factor (f) $f = TS_{\text{silvicultural activity}}/TS_{\text{natural}}$		3		—	
14 Estimated increase in soil delivered to the stream channel due to the proposed silvicultural activity (TS) in tons $TS_{\text{silvicultural activity}} = TS_{\text{natural}} \times f$		—		—	

NUMBER OF SOIL MASS MOVEMENTS BY SLOPE CLASS OR POSITION CATEGORY

The soil mass movement recorded previously by type and cause must be differentiated by slope class or category. Debris avalanches-debris flows are differentiated by slope class which is based upon slope steepness. There are three classes: *a* is greater than 35° (70%), *b* is less than 35° (70%), and greater than 28° (53%), and *c* is less than 28° (53%). Slump-earthflows are differentiated by position on the slope. There are four position categories: *a'* is adjacent to the stream, *b'* is the lower 1/3 of the slope, *c'* is the middle 1/3 of the slope, and *d'* is the upper 1/3 of the slope. This information is recorded on worksheet V.6, step 4 for slope classes and step 5 for slope position categories.

TOTAL VOLUME RELEASED BY SLOPE CLASS OR POSITION CATEGORY

For both the proposed silvicultural activity area and the area previously subjected to a silvicultural activity, the total volume of soil mass movement (V_t) by type and slope class *(a,b,c)* or position category *(a',b',c',d')* is computed. The average volume per failure (V_A) is multiplied by the number of failures in each slope class *(a,b,c)* or position category *(a',b',c',d')* and recorded on worksheet V.6, step 6. For example, if the average volume per failure (V_A) was equal to 3,441 ft^3 (162 m^3) and there were two debris avalanches-debris flows in the 28° to 35° slope class *(b)*, the total volume for that soil mass movement type and slope class *(b)* would equal 6,882 ft^3 ([illegible]24 m^3) or 3,441 ft^3 × 2 = 6,882 ft^3.

ESTIMATED DRY UNIT WEIGHT OF SOIL MASS MOVEMENT

Estimate the dry unit weight (γ_d) of the soil materials included in the failures (V), expressed in pounds/cubic foot. Use soil samples from the assessed area for this determination if possible. Otherwise, use the values for typical soils provided in table V.9. For example, the soil was measured, the dry unit weight was 99 lb/ft^3 (1.57 g/cm^3). The dry unit weight of soil material is recorded on worksheet V.6, step 7.

Table V.9—Unit weight of typical soils in the natural state (Terzaghi 1953)

Description	**Unit weight**	
	γ_d[1]	γ_d
	lb/ft^3	g/cm^3
Uniform sand, loose	90	1.43
Uniform sand, dense	109	1.75
Mixed-grained sand, loose	99	1.59
Mixed-grained sand, dense	116	1.86
Glacial till	132	2.12

[1] γ_d = unit weight in dry state.

COMPUTE TOTAL WEIGHT RELEASED PER SLOPE CLASS OR CATEGORY

Estimate the total weight of material (W) released per slope class *(a,b,c)* or category *(a',b',c',d')*. For the previously disturbed site (that area subjected to a past silvicultural activity), differentiate between natural and man-induced failures. For example, if the dry unit weight was 99 lb/ft^3 and the total volume released by debris avalanche-debris flow with a slope class of 28° to 35° was 6,882 ft^3, the total weight released for this slope class would be 681,318 lb or 6,882 ft^3 × 99 lb/ft^3 = 681,318 lb. This is converted to tons by dividing by 2,000 lb/ton or 681,318 lb divided by 2,000 lb/ton = 341 tons (309 metric tons). These values are recorded on worksheet V.6, step 8, by slope class *(a,b,c)* or position category *(a',b',c',d')*, type of mass movement, and for the previously disturbed site, natural vs. man-induced failures.

SLOPE IRREGULARITY BY SLOPE CLASS OR POSITION CATEGORY

Estimate, by slope class *(a,b,c)* or position category *(a',b',c',d')*, the gross irregularity of the slope within the area of the proposed silvicultural activity and the area of the past silvicultural activity. Two general classifications are used: smooth and irregular. Smooth slopes generally have a uniform profile with a few major breaks or benches which may serve to trap and collect soil mass movement material. Incipient drainage depressions and intermittent drainages have a constant grade and lead directly to main drainage channels. Irregular slopes generally have an uneven profile with frequent benching or breaks, which tend to trap and collect soil mass movement material. Incipient drainage depressions and intermittent drainageways have an uneven grade with frequent grade flattening and changes in direction. The classification is recorded on worksheet V.6, step 9.

ESTIMATE DELIVERY POTENTIAL

Determine the percentage of soil mass movement material delivered (D) to the stream channel. An estimated delivery relationship is presented in figure V.11, for debris avalanches-debris flows, and is based upon the slope class *(a,b,c)* and irregularity. An estimated delivery relationship is presented in figure V.12 for slump-earthflows and is based upon the slope position category *(a′,b′,c′,d′)*. Delivery in percent, is recorded on worksheet V.6, step 10. For example, the delivery potential of a debris avalanche-debris flow on a smooth 29° (55%) slope is 30%.

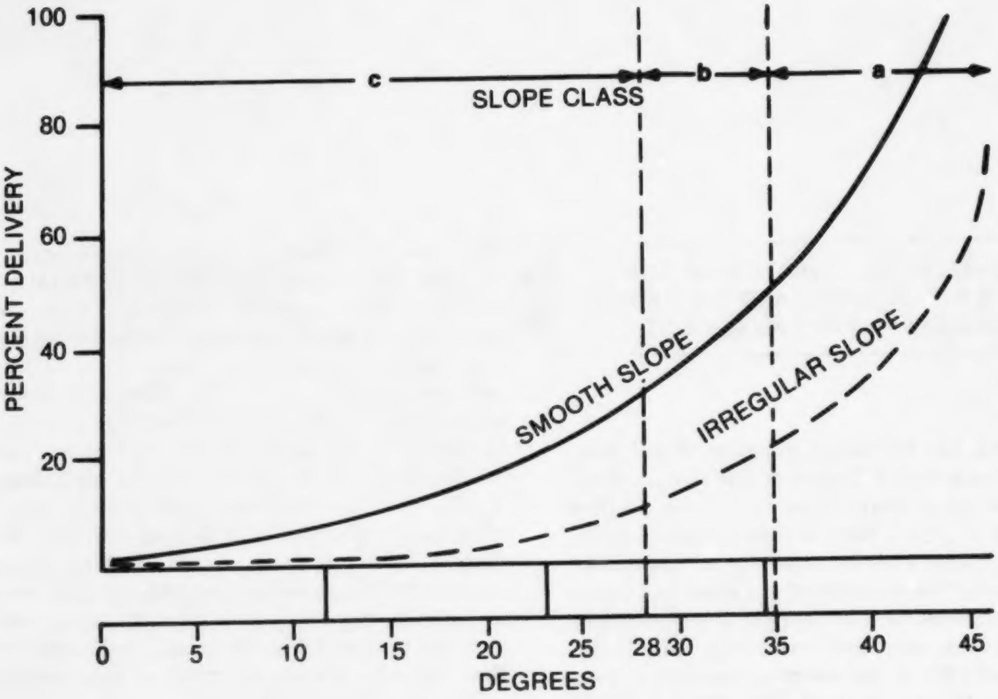


Figure V.11—Delivery potential of debris avalanche-debris flow material to closest stream.

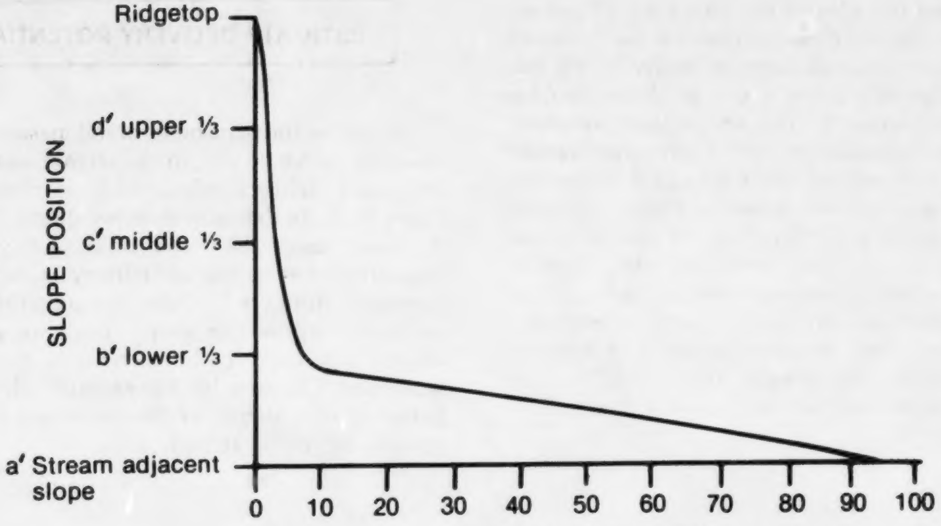


Figure V.12—Delivery potential of slump-earthflow material to closest stream.

ESTIMATE TOTAL QUANTITY OF SOIL DELIVERED PER SLOPE CLASS OR POSITION CATEGORY AND TOTAL AMOUNT

Determine the estimated quantity of soil mass movement material delivered to the stream channel (S) for each slope class *(a,b,c)* or position category *(a′,b′,c′,d′)*. For the area subjected to the past silvicultural activity, separate by natural vs. man-induced. The quantity of soil mass movement material delivered to a stream (S) is computed by multiplying the estimated total weight of released soil material (W) by the delivery potential (D) expressed as a decimal percent. This should be done for each slope class or position category. For example, if the total weight of a released debris avalanche-debris flow with a slope class of 28° to 35° class *(b)* was 341 tons, and the delivery potential was 30 percent, the amount of material delivered to a stream channel would be 102 tons or 341 tons × 0.3 decimal percent. These values are recorded in worksheet V.6, step 11. The total quantity of soil mass movement material (TS) delivered to the stream channel is computed by summing the material delivered by each slope class *(a,b,c)* or position category *(a′,b′,c′,d′)*. The total quantity delivered is recorded on worksheet V.6, step 12. For example, if the slope classes *(a,b,c)* for debris avalanche-debris flow had the following values: S_a = 171 tons, S_b = 102 tons, and S_c = 26 tons, the total quantity of material delivered to the stream channel by debris avalanche-debris flows would be equal to 299 tons. If slump-earthflows were present or possible, these values *(a′,b′,c′,d′)* would also be summed and added to the debris avalanche-debris flow value to get the quantity of total sediment delivered to the stream (TS).

The computation provides an estimate of the average total volume of material delivered to the stream channel (TS) in the area of proposed silvicultural activities under natural conditions and can be used directly in "Chapter VI: Total Potential Sediment."

ESTIMATE AN ACCELERATION FACTOR TO ACCOUNT FOR THE INCREASED DELIVERY DUE TO THE SILVICULTURAL ACTIVITY (MAN-INDUCED)

Estimate the change in sediment delivery to the stream channel on the previously disturbed area as a result of all silvicultural activities by comparing quantities and delivery rates for both natural and man-induced failures. The acceleration factor (f) is estimated by dividing the total quantity of soil delivered to the stream channel due to silvicultural activities (man-induced) (TS silvicultural activity) by that due to natural causes (TS natural), record on worksheet V.6, step 13. For example, if the quantity of soil delivered due to silvicultural activities was 299 tons and that delivered due to natural cause was 101 tons, the acceleration factor (f) would be 3.0. The acceleration factor is recorded on worksheet V.6, step 13. Note total from both natural and man-induced failures would be equal to 299 tons (silvicultural activity) plus 101 tons (natural) or 400 tons.

ESTIMATE INCREASED SOIL DELIVERY DUE TO THE PROPOSED SILVICULTURAL ACTIVITY

Estimate the increase in amount of soil mass movement material that would be delivered from the area being considered for the proposed silvicultural activity. The total quantity of soil mass movement material (TS) delivered to the stream channel (natural conditions) is multiplied by the acceleration factor (f) estimated from a site previously subjected to similar silvicultural activity, record on worksheet V.6, step 14. For example, if the existing natural condition delivered a total quantity of soil mass movement material to the stream channel of 64 tons and the acceleration factor estimated from a similar site subjected to a similar silvicultural activity was 3.0, the estimated potential soil mass movement material delivered to the stream channel would be equal to 192 tons. This completes the procedure for determining increased soil delivery.

APPLICATIONS, LIMITATIONS, AND PRECAUTIONS

Relating magnitude of management impact to hazard index ranking has the shortcoming that once a site is ranked as high hazard, alternate management practices do not change the estimate of management impact. Where data permit, quantification of hazard index should be set up so that management-caused changes in hazard index are directly proportional to degree of accelerated erosion. Such a system would permit realistic assessment of various management alternatives on the mass erosion rate. However, additional studies are needed to quantify the impact of numerous silvicultural activities.

CONCLUSIONS

This procedure is designed to quantify the potential volume of soil mass movement material that is delivered to the closest drainageway as a result of a proposed silvicultural activity. The analysis is conducted on areas that have previously been delineated as unstable. It should be reemphasized that if the user does not have experience in delineating unstable or potentially unstable areas, additional assistance from qualified specialists should be obtained.

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Chapter VI

TOTAL POTENTIAL SEDIMENT

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INTRODUCTION

One of the most significant and frequent water quality changes resulting from silvicultural activities is accelerated, inorganic sediment discharge. Land and stream systems are constantly adjusting to changes in the erosional rates of slopes and the transport capabilities of the stream systems draining those slopes. Silvicultural activities can exponentially affect the rate of sediment discharge, depending upon the sensitivity of the slopes and the affected stream reaches and the degree and duration of impact.

It is difficult to predict absolute changes because of the time-space variability inherent in stream systems; however, several consistent analytical relationships involving the prediction of sediment supply and transport are available. These relationships can be used to estimate relative amounts of change in potential sediment discharge resulting from proposed silvicultural activities.

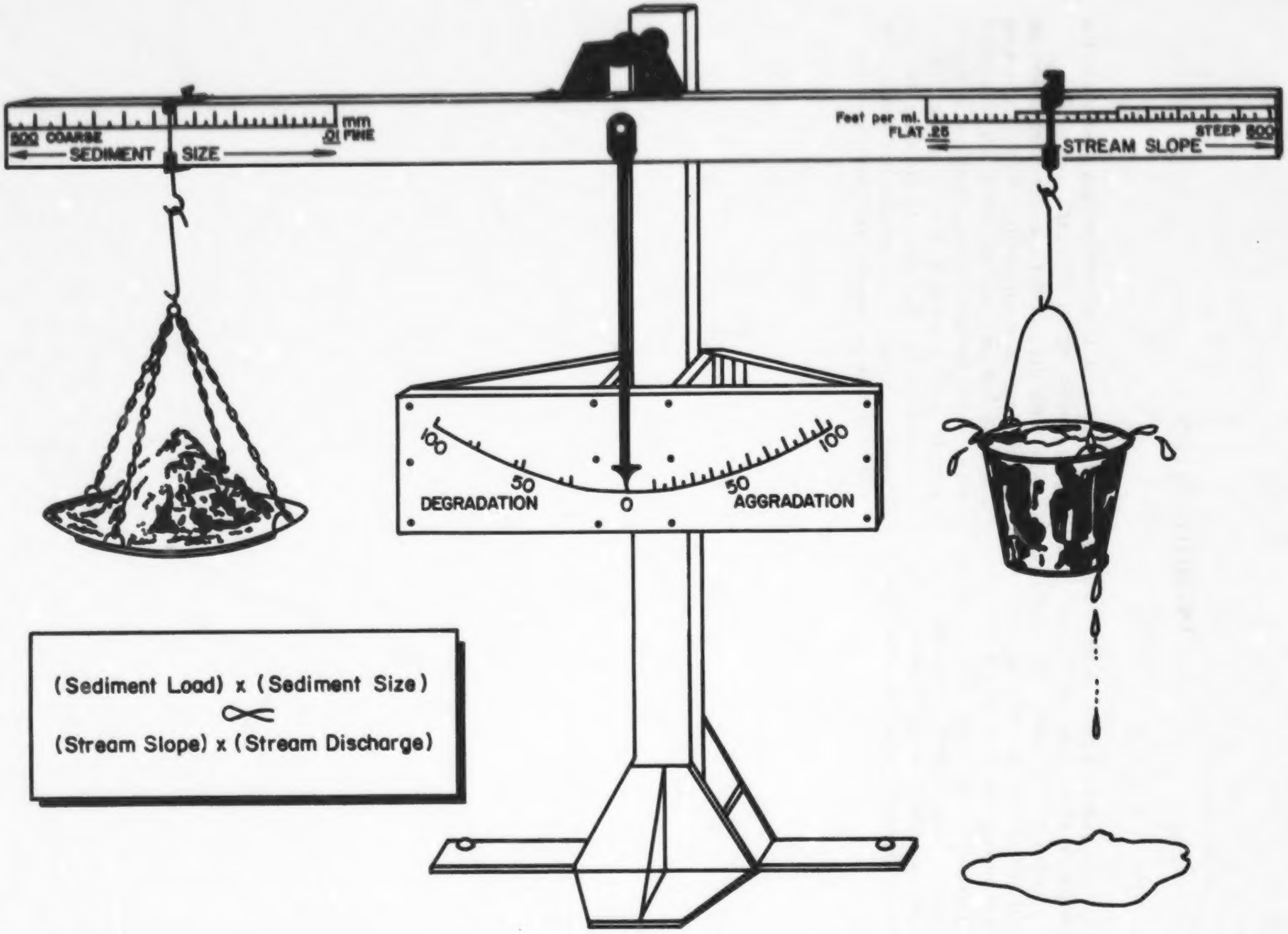


Figure VI.1.—Diagrammatic relationship of a stable channel balance (Lane 1955).

DISCUSSION

In most cases, sediment objectives are stated in terms of acceptable increases in suspended sediment based on state and federal laws and physical site conditions. The analysis procedure estimates the amount of potential change in suspended sediment discharge and bedload sediment discharge as well as qualitative effects on channel stability.

Evaluation of potential sediment changes requires use of analytical procedures to make a consistent comparative analysis of baseline and accelerated levels. The procedures outlined in this handbook are not designed to predict absolute values obtained for any given year. They do however relate to the potential changes in the physical processes, as affected by silvicultural activities. The interpretation made from the results of theses analyses requires a great deal of professional judgment.

STREAM CHANNEL MORPHOLOGY AND WATER QUALITY

Streams are dynamic systems where configurations are adjusted in response to eight interrelated variables — width, depth, gradient, velocity, roughness of bed and bank materials, discharge, concentration of sediment, and size of sediment debris (Leopold and others 1964). A change in one or more of the eight noted variables produces changes in channel processes with a net effect of either aggradation or degradation. However, a counteractive change occurs over time in the other variables to prevent continued stream aggradation or degradation (Shen 1976).

When a stream system is in a state of dynamic equilibrium, the eroded material supplied to and stored in the stream is balanced with the energy available to transport the material. As changes affect sediment supply and stream energy, the channel system undergoes a series of adjustments and is in disequilibrium. Under wildland watershed conditions, dynamic equilibrium is not a steady state from year to year, and annual variations in scour or deposition may occur. These channel adjustments not only affect channel stability, but generally result in significant changes in sediment discharge.

Lane (1955) diagrams a stability relationship between sediment supply and stream energy (fig. VI.1), indicating stream slope and discharge (energy) are proportional to sediment load and sediment size (supply). Process changes which affect stream slope, stream discharge, sediment size and concentration may create unstable conditions which can result in stream channel aggradation and/or degradation.

Shen and Li (1976) describe a relationship where sediment discharge is a function of the supply rate and transport capability of various sized particles under a particular flow regime (fig. VI.2). "Washload" is that portion of the suspended load which is 0.0625 mm or smaller (silts and clays).

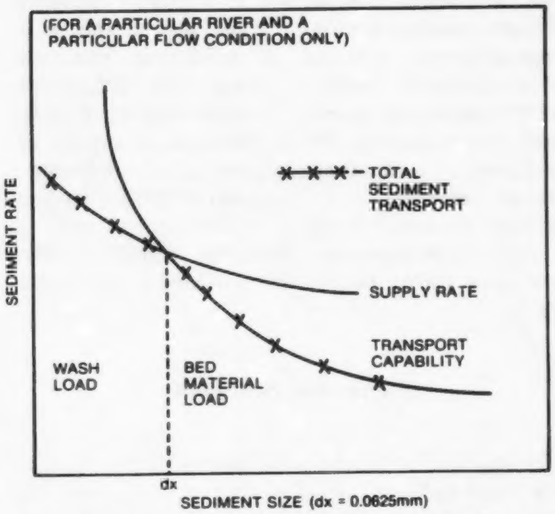


Figure VI.2.—Relationships of sediment rate and size to supply rate and transport capability (Shen and Li 1976).

Man-caused changes in channel process include increased debris, constrictions due to road fill encroachments, stream crossings, alterations in streamflow amounts and timing through vegetation modifications, introduced sediment, and direct channel alterations. These impacts affect the rate and magnitude of channel adjustments and may affect channel erosion through lateral channel migration, change in bed form, and other morphological changes. Such changes are ultimately expressed as differences in sediment concentration per unit discharge and as changes in bedload transport.

The ability of streams to adjust to imposed changes varies with the type of bed and bank materials, the stability of the landform in which the stream is incised, the amount and size of sediment in the channel, the hydraulic geometry of the channel, and the runoff characteristics of the watershed.

Stream channels reflect the current watershed condition. The stability of natural channels varies by geomorphic province and by reach within the same watershed. The ability to interpret this variance in stability is important when assessing sediment discharge influenced by channel processes. A stability evaluation provides a consistent analytical comparison of stability between stream reaches within a given region and is a reproducible method of assessing channel characteristics. Stability evaluations (Pfankuch 1975) examine primarily: (1) detachability of bank and bed materials, (2) availability or supply of sediment as a function of degree of entrenchment, stored sediment, and landform adjacent to the stream, (3) direct impacts on the channel, and (4) energy forces available. Examples of streams with various stability ratings are provided in appendix VI.A.

Suspended Sediment

Suspended sediment is defined as that portion of the total sediment load in transit under varying flow regimes that is measured using depth-integrated samplers (DH-48, DS-49, 59) as described by Guy and Norman (1970). This procedure, utilizing the equal transit rate method, requires a continuous sample taken from the water surface to within 3 inches of the stream bed. Sediment size generally includes sands or smaller, but a specified size is not always predictable due to changes in stream velocities.

Suspended sediment from stream channel erosion is the major contributor to total annual sediment discharge in some streams draining forested watersheds (Anderson 1975, Striffler 1963, Rosgen 1973, Flaxman 1975, and Piest and others 1975). The sediment rating curve has been developed and used for analyzing sediment discharge for the past 40 years. A sediment rating curve is derived from values of measured suspended sediment, in milligrams/liter, correlated with stream discharge (cfs). Sediment rating curves represent changes in sediment supply and stream channel adjustments associated with the accelerated sediment introduction.

Recent applications and interpretations of the sediment rating curve approach have been used in management applications (Flaxman 1975 and Rosgen 1975a). This latter interpretation of the sediment rating curve technique is presented for use in this chapter. The sediment rating curve approach involves depth-integrated sampling for suspended sediment over a wide range of climatic situations and representative flows. Examples of typical sediment rating curves are shown in figures VI.3 and VI.4.

Most of the annual sediment discharge results from streamflow that generally occurs less than 10 percent of the time. Since streamflow is the primary variable associated with stream energy, changes in flow amounts or timing directly influence sediment discharge. Although flows vary from year to year, time-dependent plots generally are not evaluated because long-term records are required. However, flow-dependent analysis can be made based on representative flows monitored over a water year (October 1 through September 30), where variables affecting sediment concentrations are determined concurrently with stream discharge. Sampling "representative flows" involves collection of suspended sediment during various flow and seasonal conditions to detect any variability in concentration for the same flow during a water year. Significant variability can be analyzed separately. Sampling intensity depends on flow variation and anticipated supply changes. Minimum sampling stratification for the development of sediment rating curves is shown in step 3 of the procedure.

If the representative flows cannot be sampled to establish a sediment rating curve, continued monitoring into the next water year may be required. The reliability of the procedure may be reduced if representative flows, as defined, are not sampled.

The many research efforts utilizing the sediment rating curve approach are summarized in the USFS-EPA "Non-Point Water Quality Modeling, Wildland Management" (1977). Flaxman (1975) used this approach to determine the amount of channel erosion attributable to man's activities. Applications by Farnes (1975) were designed to identify changes in sediment discharge as a result of upstream changes in land use on selected watersheds in Montana. The technique is presently used as a portion of the analytical prediction techniques for determining potential changes in sediment due to timber harvest on some national forests in Montana and Idaho (USDA Forest Service 1975).

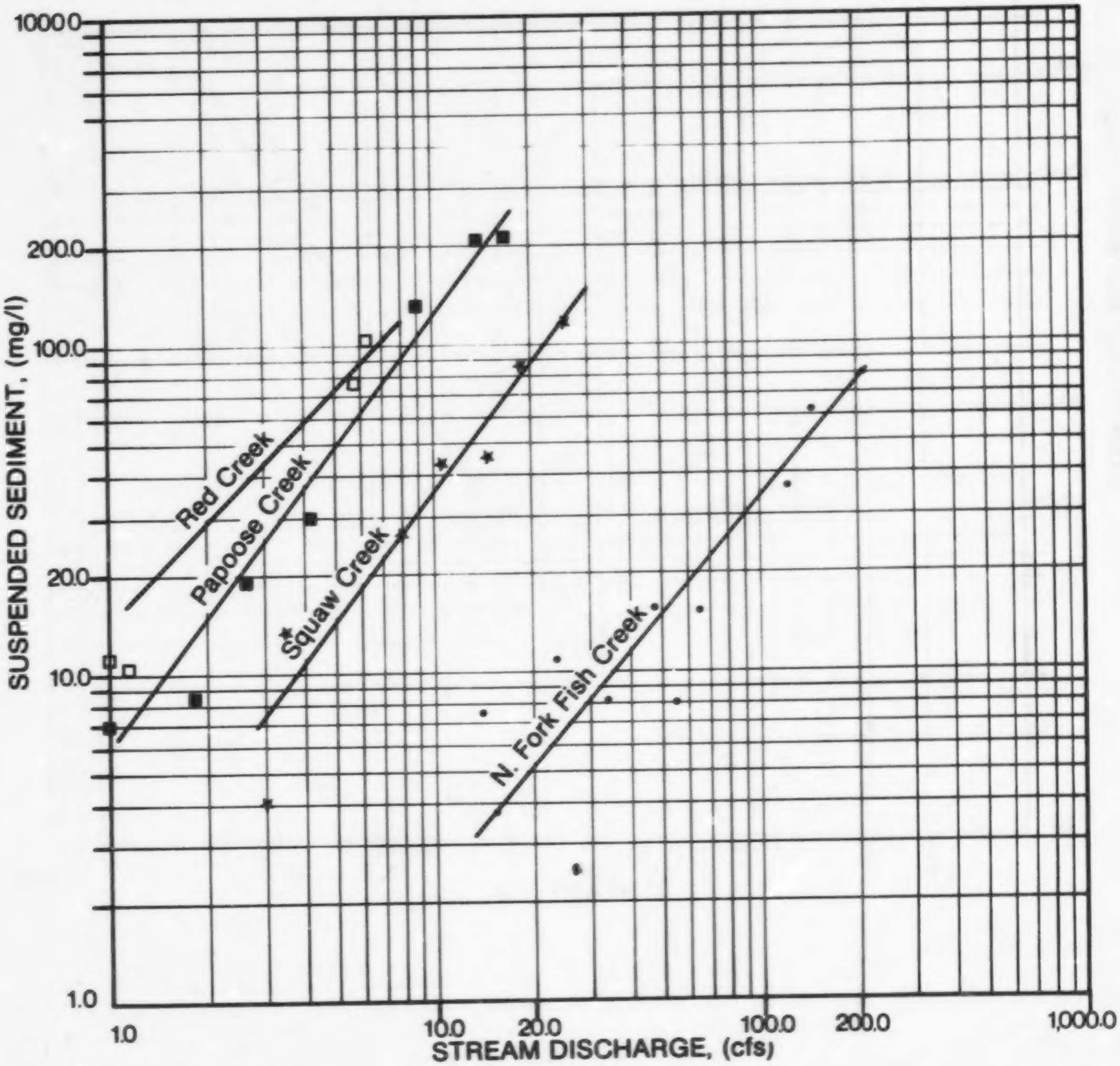


Figure VI.3—Sediment rating curves for streams in western Wyoming (Holstrom 1976).

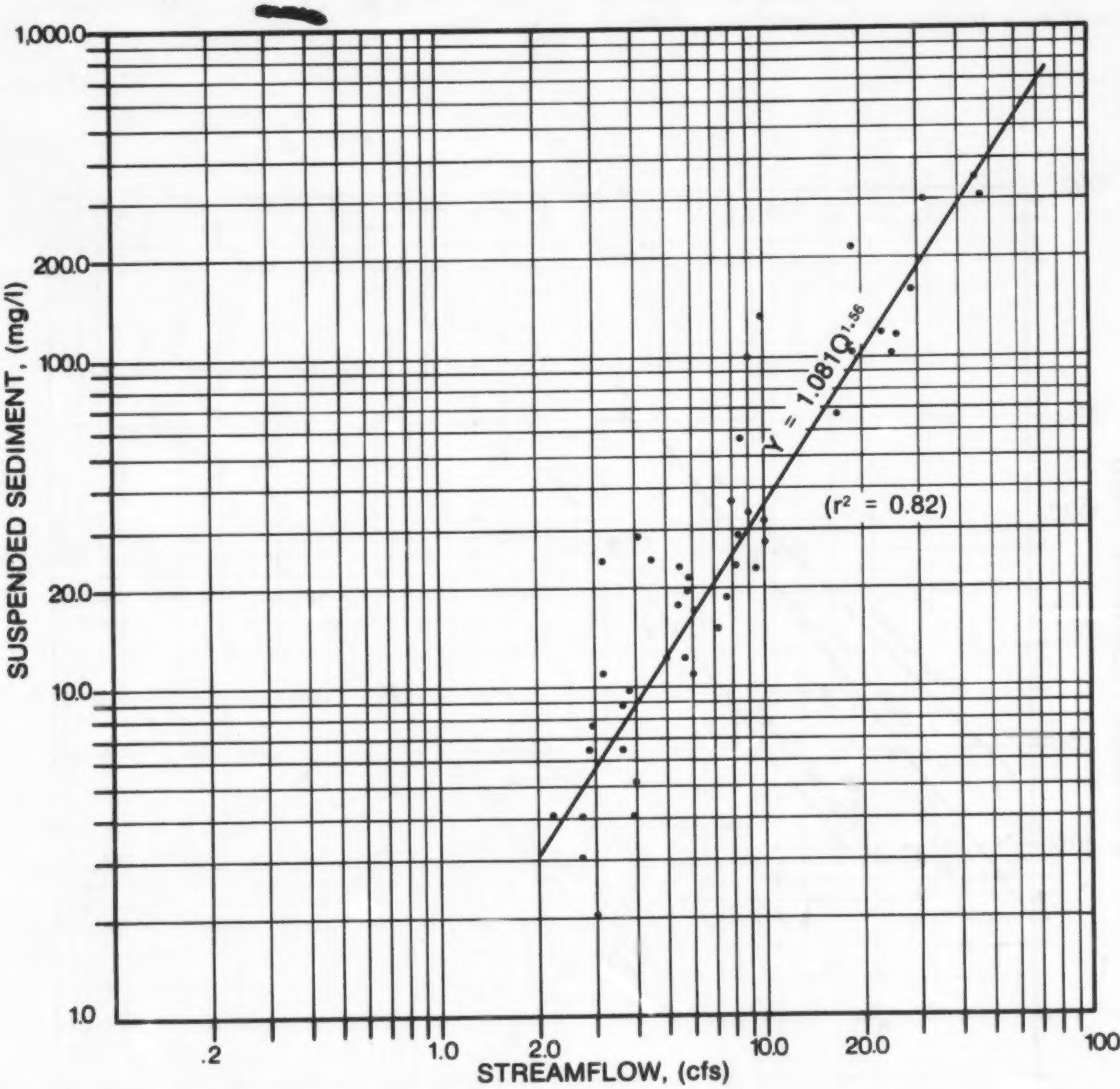


Figure VI.4.—Sediment rating curve for Needle Branch Creek, Oregon, 1964-1965 water year (Sundeen 1977).

Interpretations Of Sediment Rating Curves

Shifts in the sediment rating curve reflect both natural and man-induced changes that alter the slope and intercept of the regression equation. These shifts indicate the dynamic nature of stream channels.

Examples of changes in sediment rating curves have occurred following a major flood in 1964, which shifted the sediment rating curve a full order of magnitude on the Eel River in northern California (Flaxman 1975). Thus, an increase in stream channel sediment supply that aggraded many river reaches resulted in major channel adjustments and associated increased sediment discharge (fig. VI.5).

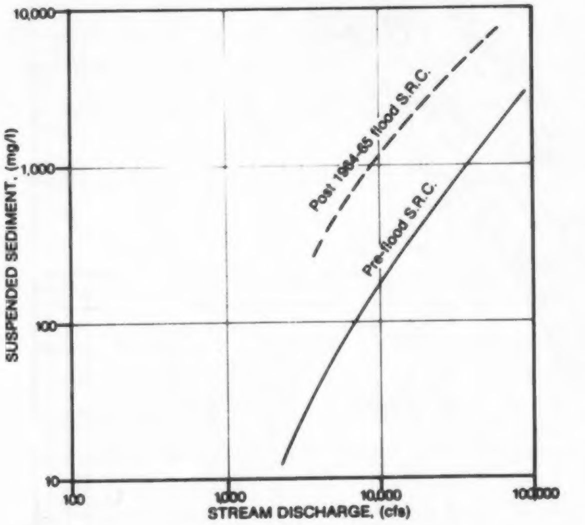


Figure VI.5.—Change in the sediment rating curve for the Eel River, Scotia, Calif., showing increases in sediment concentration per unit discharge when flood caused a change in sediment deposition (Flaxman 1975).

For any given flow on the Eel River following the flood, the sediment concentration was exponentially higher. Suspended sediment discharge under post flood condition is very sensitive to flow increases. Flaxman (1975) cited similar results from channel restoration measures applied to streams where channel erosion was a predominant source of the total annual suspended sediment discharge.

An analysis of the effects of clearcutting on sediment rating curves was recently conducted on the Needle Branch drainage, near the Oregon coast (Sundeen 1977). This analysis indicated a shift of the regression constants of the sediment rating curve following the first year of harvest (fig. VI.6). Even though the highest flood peaks occurred before harvest (due to the 1964 flood), the major shift in the sediment rating curve occurred following timber removal. The recovery of Needle Branch has been fairly rapid; in the second year following clearcutting, the sediment rating curve (1967-68) returned nearer the pre-flood condition. Under the post-flood condition, any further change in duration of bankful stage or in magnitude of peak flows due to timber harvesting will produce exponentially higher sediment discharge. These relationships agree closely with those suggested by Flaxman (1975).

The sediment rating curve technique has been used to evaluate timber sale impacts in Montana and Idaho (Rosgen 1975a). Changes in sediment supply were linked to individual sources when a surveillance monitoring program was initiated to show these "shifts" in sediment rating curves. In many instances, the major cause for the shifts and change in stability was associated with sediment supply increases by roads, debris slides and increases in stream discharge. Stream channel impacts can be evaluated through relationships developed between measured sediment rating curves and stream channel stability as explained in appendix VI.B.

Time Series Analysis-Recovery

Conceptually, it is desirable to predict not only the magnitude and direction of change in sediment rating curves, but also the time required for the sediment rating curve to return to its pre-disturbance position. However, it is beyond the state-of-the-art to actually predict a post-silvicultural activity sediment rating curve. Despite this, it is of value to qualitatively evaluate recovery to help interpret analysis results.

A qualitative procedure for determining the recovery potential of streams by morphological descriptions was developed and used in northern Idaho (Rosgen 1975c). It evaluates recovery potential based on depth of channel to bedrock, gradient, material size, and channel stability ratings. The recovery period is based on the type and dates of impact from historical records on various streams, differing channel materials, gradients, etc. Tested quantitative techniques for determining recovery periods and rates at which the sediment rating

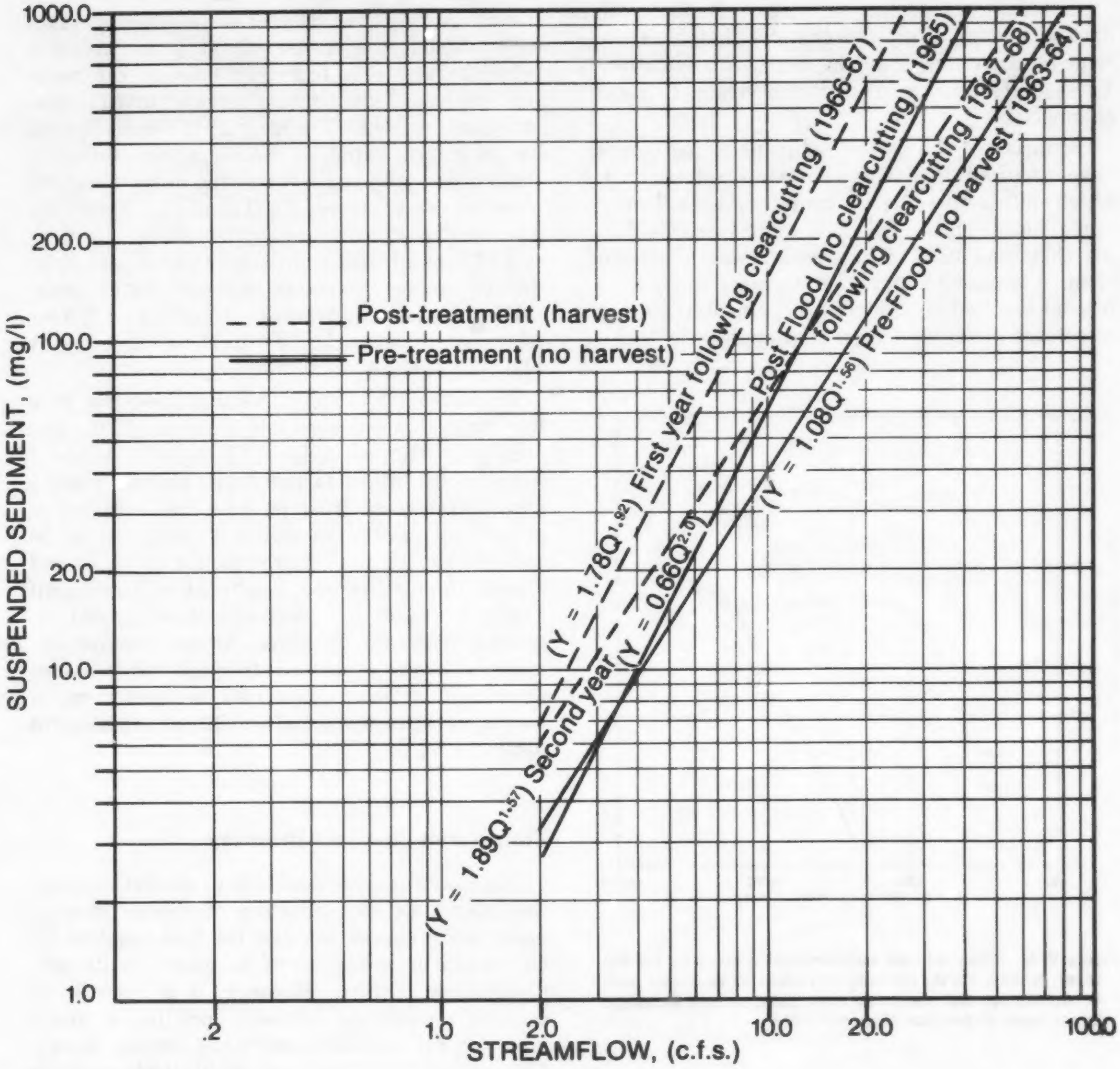


Figure VI.6.—Change in sediment rating curves for Needle Branch Creek, Oregon, showing the shift in rating curves due to 1964 flood and silvicultural operations (Sundeen 1977).

curves return to pre-silvicultural activity conditions have not been developed. A technique that may have potential application is presented in appendix VI.C. Any recovery technique should be developed locally, because great variation can be expected in regional relationships of recovery response.

Turbidity

Turbidity is an optical characteristic of water quality, whereas suspended and bedload sediment are related to the actual rate and weight of transported inorganic soil particles. It is often possible to establish a correlation between turbidity and suspended sediment concentration. A relationship can be established using regression analysis based on local data if the analysis is: (1) conducted on the same stream reach under a wide range of flow conditions, and (2) conducted so that the turbidity sample is also depth integrated. If significant correlations can be established between the two water quality characteristics, one may be inferred from the other. Turbidity will not be directly analyzed in this chapter.

Bedload Determination

Bedload is inorganic soil particles of various sizes which are transported in contact with or near the streambed. Bedload transport becomes a predominant factor during major runoff events, where sufficient energy is available to dislodge and transport the larger sized particles generally armored in the streambed or supplied to the stream from the channel sides and slopes. Studies of mountain streams in northern Idaho have shown bedload to be less than 5 percent of mean annual total sediment discharge when measured concurrently with suspended sediment on first to third order streams (Rosgen 1974). Emmett (1975) determined that bedload transport for gravel bed streams in the upper Salmon River area was approximately 1 to 10 percent of the suspended sediment load transported. However, evaluation of the basic processes involved in bedload transport is valuable to determine the potential changes in stream channel stability and in associated suspended sediment concentrations.

Numerous empirical bedload transport equations are described in the EPA-USFS "Non-Point Water Quality Modeling Wildland Management" (1977). However, data for validation of natural channels and for testing these bedload transport equations are limited; therefore, it is difficult to convert them to quantitative expressions of water quality.

Evaluation Of Bedload Discharge Using Bedload Rating Curves

The procedure presented in this chapter requires bedload sampling concurrent with suspended sediment sampling. The method for establishment of bedload rating curves is similar to the procedure for developing suspended sediment rating curves. Bedload is measured from the bed surface to 3 inches above the bed using a pressure differential type sampler (Helley and Smith 1971) during representative flows in 1 water year. An example of a bedload rating curve is shown in figure VI.7.

The calculations utilizing the bedload rating curve procedure are designed to:

1. Predict a quantitative change in bedload sediment discharge by comparing changes in amounts and seasonal distribution of excess water;
2. Determine the relative contributions of suspended and bedload sediment;
3. Provide data to develop local bedload-stream power relationships to assess potential stream channel changes and resulting changes in bedload sediment discharge.

Effects Of Bedload Changes On Stream Channels And Sediment Discharge

The potential impact on stream channels due to introduced sediment and/or changes in stream power is calculated using procedures similar to those presented by Leopold and Emmett (1976). This requires the development of regional or local bedload stream power relationships expressed as a function of the size of material being transported (fig. VI.8). At high flows, transport rates become directly proportional to stream power, as suggested by Bagnold (1966). This is shown in figure VI.8, where the ratio of transport rate (i_b) to unit stream power (ω) is represented as $i_{b/\omega} = 100\%$. Stream power, as used in the proposed method, is defined as the unit weight of water (1,000 kg/m^3) times the discharge of water (m^3) per meter width over the total stream width (m) times the gradient of the

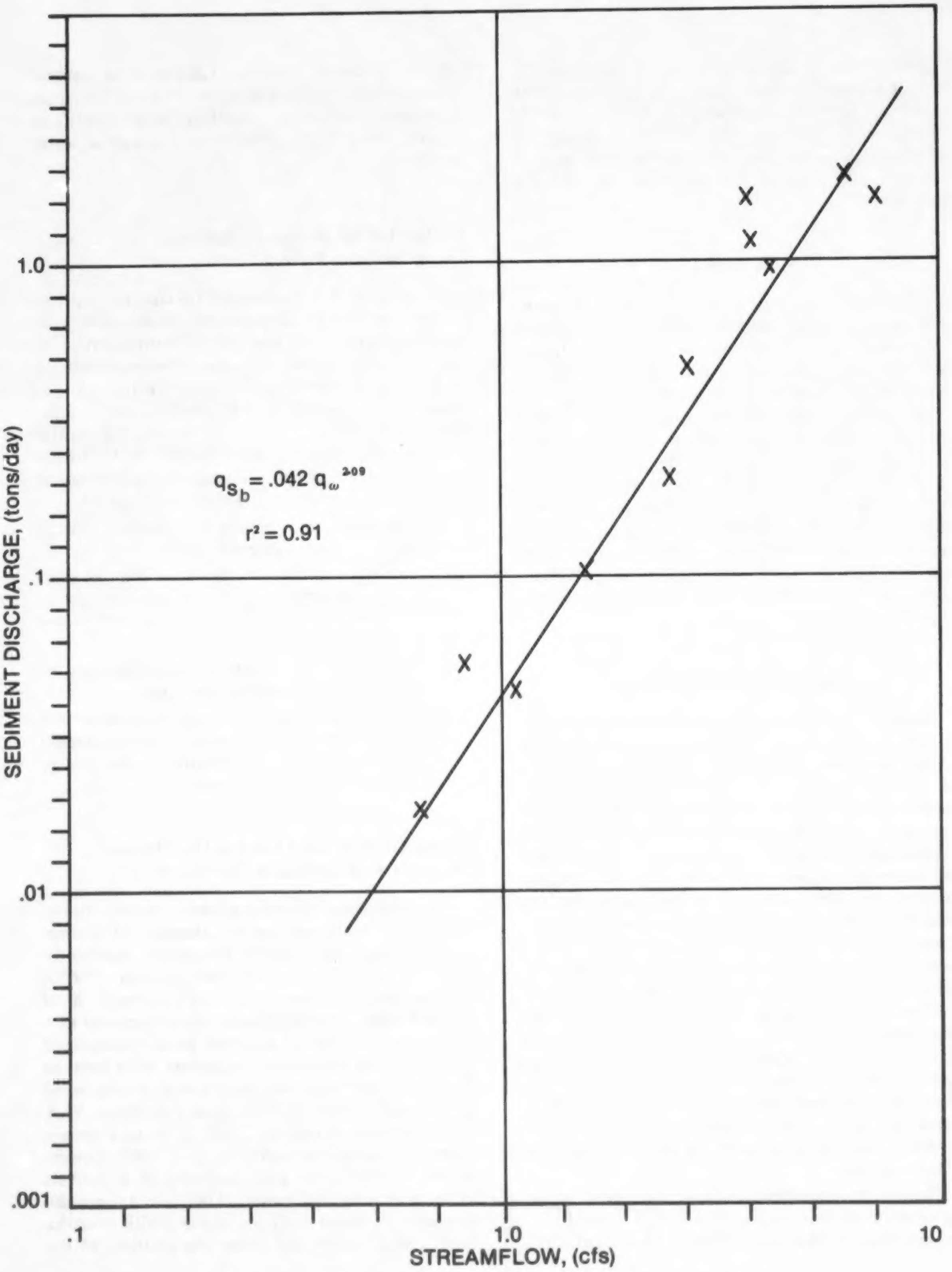


Figure VI.7.—Bedload rating curve, central Idaho stream (Megahan 1978).

stream (m/m) (Leopold and Emmett 1976). The integration of cross-sectional area and velocities assumes rectangular banks for the calculation. To develop this relationship, it is necessary to measure particle size of transported material, water surface slope, stream discharge, and stream width.

The locally derived stream power-bedload transport rate relationship should be calculated using the same principles as in the regression relationships of suspended sediment and bedload transport to streamflow.

The objective is to estimate the potential for stream channel scour and/or deposition caused by direct impacts that change the stream power variables (surface water slope and bankful width). Introduced potential sediment volume and particle size from soil mass movement are qualitatively evaluated, based on the available stream power and related sediment transport rates under bankful discharge.

Effects Of Direct Channel Impacts On Bedload Sediment Discharge

Effects of silvicultural activities on the stream power variables and associated sediment transport can be calculated. Activities that change local surface water slope, discharge, and bankful stream width can be affected by stream channel encroachment of road fills, logging debris, and stream crossings. Potential changes in bedload transport are obtained through calculations involving relationships similar to those depicted in figure VI.8.

Field evaluations of channel alterations resulting from certain silvicultural activities will provide information on changes in stream width and surface water slope as measured above versus below channel impact areas. A change in stream power (assuming no change in sediment supply) would result in a direct change in bedload discharge.

Effects Of Sediment Supply Changes And Stream Power Reductions On Stream Channels

Channel effects caused by introduced sediment from soil mass movement may be evaluated using the bedload transport rate-stream power relationship on the stream reach directly below the source. A calculation involving bankful discharge, bankful width and surface slope determines the instantaneous maximum bedload transport rate. Sediment deposition in the channel may result if the potential delivered soil mass movement volume and change in particle size exceeds the maximum potential transport rate under a given stream power.

A calculation involving bankful discharge is needed if extrapolation of the bedload transport rate-stream power relationship is needed above the third order reach. Riggs (1976) presents a procedure for determining bankful discharge. This approach involves a relationship between stream slope and velocity, eliminating the need to estimate a roughness coefficient to obtain velocity. The bankful stage determination uses procedures documented by Williams (1977), where a channel configuration indicating a bankful stage is observable on the upper limit of the "active floodplain."

A reduction in stream power caused by a debris dam would yield lower transport rates. Assuming no reduction in sediment availability, the differences in sediment yield may result in local deposition or stream aggradation. The potential for deposition or aggradation is evaluated in the detailed procedures recommended in this chapter. Until such benchmark references or long-term data can be collected and analyzed, only qualitative predictions of stream channel changes can be made.

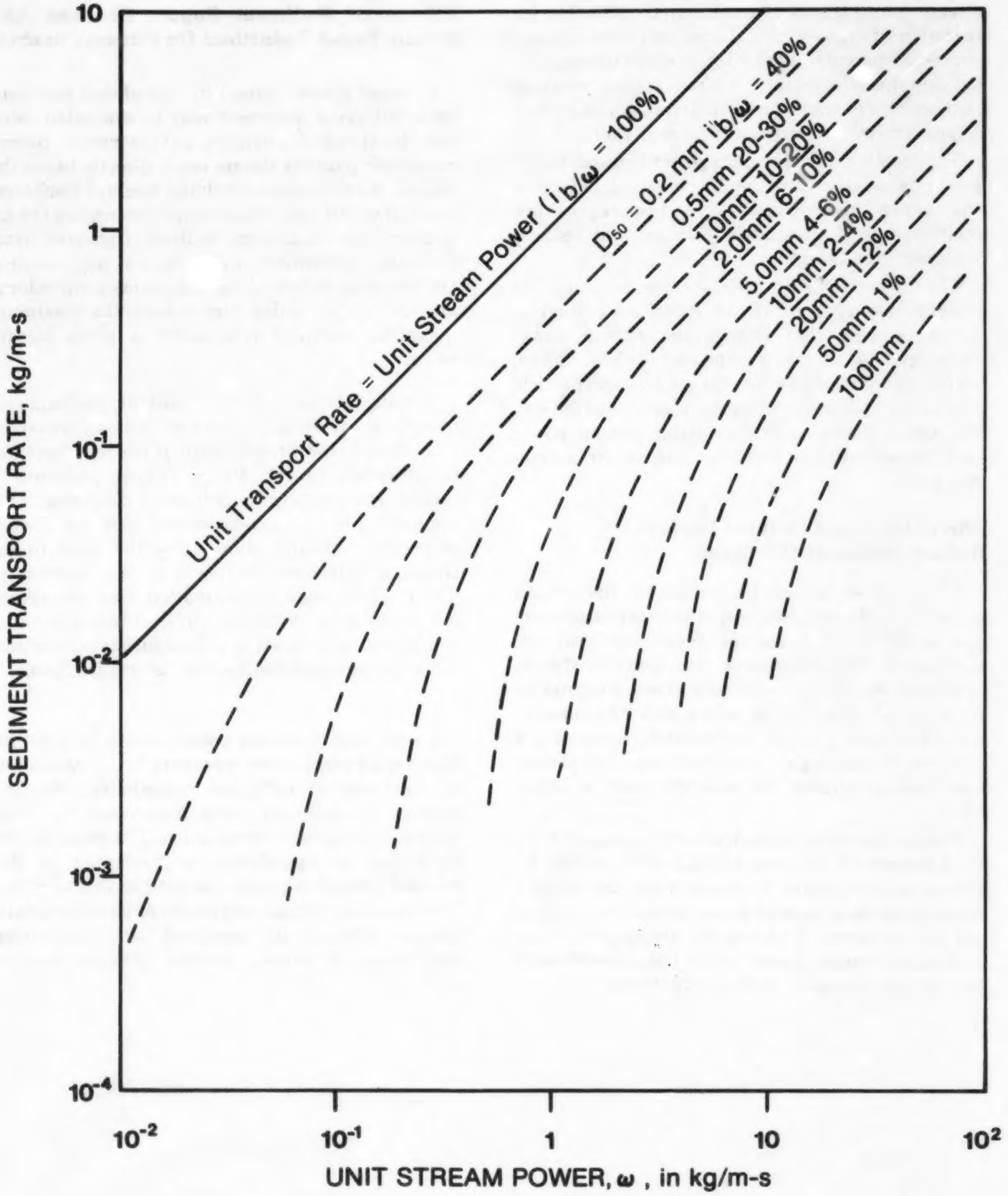


Figure VI.8.—Relationship of bedload transport and stream power for the East Fork River, Wyoming (Leopold and Emmett 1976).

THE PROCEDURE

The analysis procedure for determining potential changes in total sediment discharge is sequentially diagrammed in the procedural flow chart, figure VI.9. The following stepwise procedural description and discussion correspond with the procedural flow chart and provide directions for completing the analysis. Worksheets provided for the analysis are referenced where applicable. Table VI.1 provides a summary of all data input required to use the total sediment discharge procedure.

The following assumptions are inherent in this analysis procedure:

1. No distinction will be made between material detached from the channel banks and that previously deposited on the streambed and channel bars which is available for redistribution under varying flow regimes.
2. Increases in stream discharge exponentially increase suspended sediment and bedload sediment. Statistical relationships can be established for sediment rating curves.
3. Suspended sediment rating curves represent the existing relationship between sediment availability and stream discharge for a particular stream reach and watershed area. Temporal and spatial distribution of sediment is not addressed in this procedure. For the purpose of this analysis, temporal and spatial distribution of sediment is assumed to be constant.
4. The procedure is applicable to watershed basins of third order size.
5. The size of material delivered to streams from surface erosion is assumed to be silt and clay (washload) or smaller than .0625 mm.
6. All of the introduced washload sediment is transported through individual stream reaches (i.e., no storage is calculated, and the stream has sufficient energy to transport this sediment size).
7. A relationship can be developed between sediment transport rate and stream power through measurements of stream slope, discharge, bedload transport rate, and particle size (D_{50} = particle size for which 50 percent of the sediment mixture is finer).
8. Water surface slope does not change with water surface elevation (stage).

The prediction techniques presented in the analysis section are not recommended to replace local data or transport prediction capability, when they are available. The analysis provides the basic process relationships needed for evaluation until local data become available. A monitoring program to measure pre- and post-silvicultural activity sediment concentrations for the various flow regimes would help verify the sediment discharge predictions. Baseline channel geometry surveys should also be conducted to determine changes in stream aggradation or degradation, lateral migration, or other channel adjustments.

It is important to notice that all the calculations through step 20 are designed to relate quantitatively to the potential sediment discharge at the third order reach. Step 21 is a qualitative interpretation for various reaches in the subdrainage as affected by stream channel response to introduced sediment from soil mass movement, and channel encroachments.

DETAILED ANALYSIS PROCEDURE

Step 1. Subdrainage and Stream Reach Characterization

Procedure: Select a representative third order stream reach where data collection is required.

Discussion: For quantitative evaluations (steps 1-20) this stream reach will be used. For qualitative evaluation (step 21), individual first through third order streams will be selected.

Step 2. Determination of Pre- and Post-Silvicultural Activity Hydrographs or Flow Duration Curves

Procedure: Obtain the output from the hydrologic analysis for the selected third order drainage as outlined in chapter III. Outputs required are:

a. Potential increase in total annual water production;
b. Seasonal distribution of water (based on 6- or 7-day averages) (figs. VI.10a or VI.10b) represented as either hydrographs or flow duration curves for:

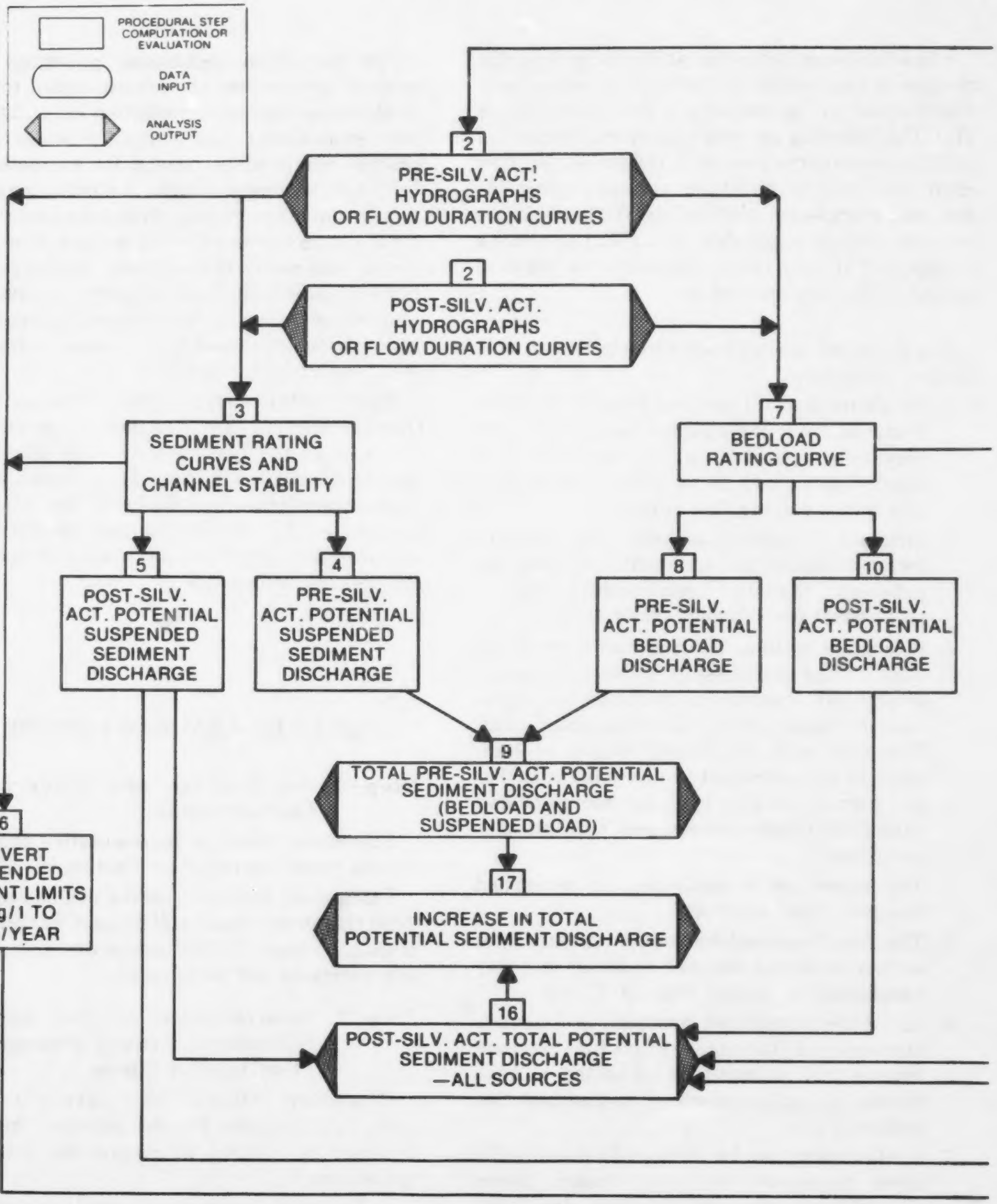
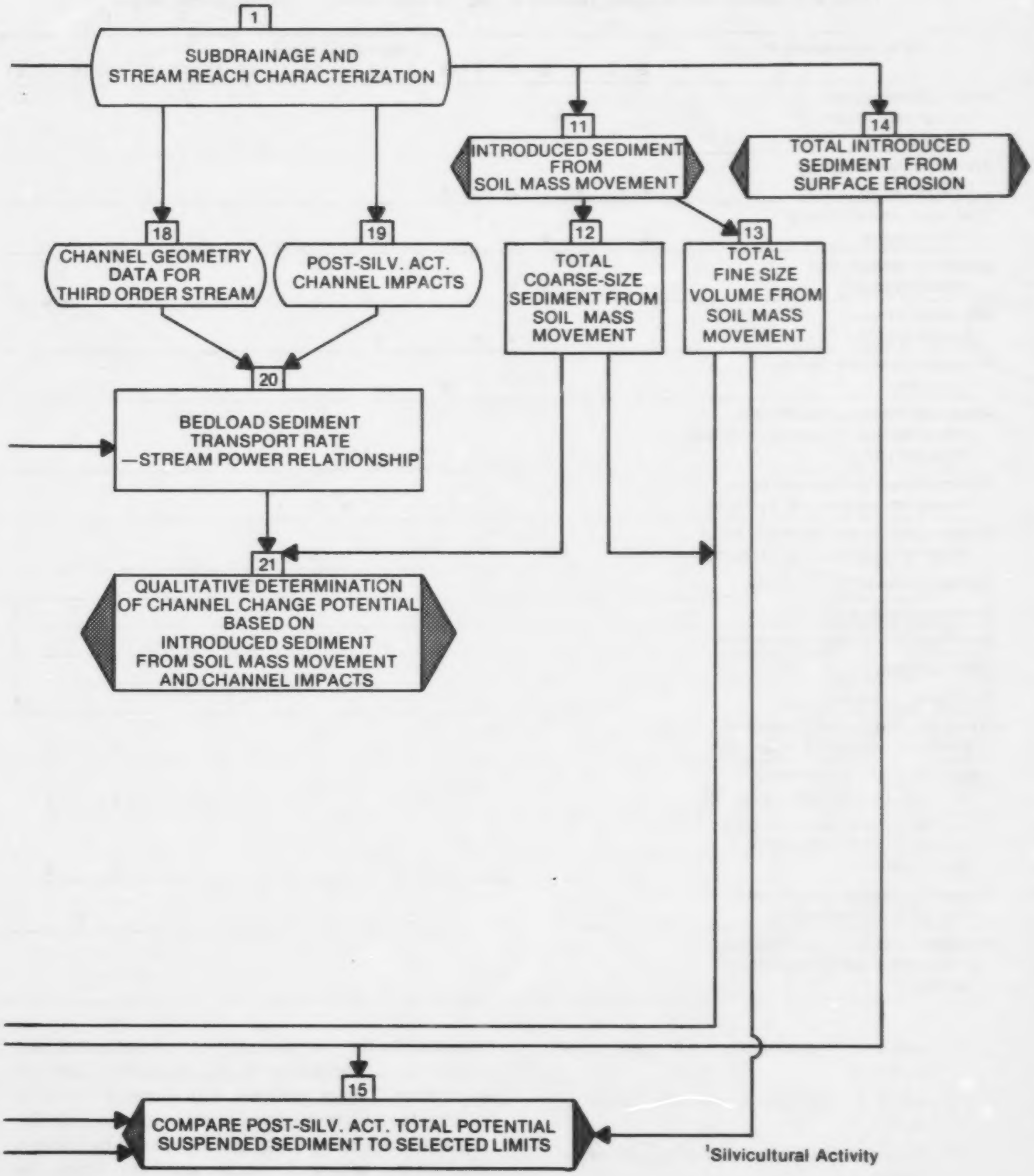

PROCEDURAL STEP COMPUTATION OR EVALUATION
DATA INPUT
ANALYSIS OUTPUT
2
PRE-SILV. ACT. HYDROGRAPHS OR FLOW DURATION CURVES
2
POST-SILV. ACT. HYDROGRAPHS OR FLOW DURATION CURVES
3
SEDIMENT RATING CURVES AND CHANNEL STABILITY
7
BEDLOAD RATING CURVE
5
POST-SILV. ACT. POTENTIAL SUSPENDED SEDIMENT DISCHARGE
4
PRE-SILV. ACT. POTENTIAL SUSPENDED SEDIMENT DISCHARGE
8
PRE-SILV. ACT. POTENTIAL BEDLOAD DISCHARGE
10
POST-SILV. ACT. POTENTIAL BEDLOAD DISCHARGE
9
TOTAL PRE-SILV. ACT. POTENTIAL SEDIMENT DISCHARGE (BEDLOAD AND SUSPENDED LOAD)
6
CONVERT SUSPENDED SEDIMENT LIMITS IN mg/l TO TONS/YEAR
17
INCREASE IN TOTAL POTENTIAL SEDIMENT DISCHARGE
16
POST-SILV. ACT. TOTAL POTENTIAL SEDIMENT DISCHARGE —ALL SOURCES

Figure VI.9—Procedural flow chart for estimating potential changes in total sediment discharge.


1
SUBDRAINAGE AND STREAM REACH CHARACTERIZATION
11
INTRODUCED SEDIMENT FROM SOIL MASS MOVEMENT
14
TOTAL INTRODUCED SEDIMENT FROM SURFACE EROSION
18
CHANNEL GEOMETRY DATA FOR THIRD ORDER STREAM
19
POST-SILV. ACT. CHANNEL IMPACTS
12
TOTAL COARSE-SIZE SEDIMENT FROM SOIL MASS MOVEMENT
13
TOTAL FINE SIZE VOLUME FROM SOIL MASS MOVEMENT
20
BEDLOAD SEDIMENT TRANSPORT RATE —STREAM POWER RELATIONSHIP
21
QUALITATIVE DETERMINATION OF CHANNEL CHANGE POTENTIAL BASED ON INTRODUCED SEDIMENT FROM SOIL MASS MOVEMENT AND CHANNEL IMPACTS
15
COMPARE POST-SILV. ACT. TOTAL POTENTIAL SUSPENDED SEDIMENT TO SELECTED LIMITS

[1] Silvicultural Activity

Figure VI.9—continued

Table VI.1.—Summary of input required to use the total sediment discharge procedure.

Data requirements	Procedural steps																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Aerial photography and stream reach selection	x																				
Pre-silvicultural activity hydrographs		x		x		x		x													
Post-silvicultural activity hydrographs		x			x					x											
Measured suspended sediment (mg/l)			x	x	x	x															
Measured stream discharge (cfs)			x	x	x	x	x	x		x											
Measured bedload sediment (tons/day)							x	x		x											
Allowable maximum sediment concentration (from water quality objective) (mg/l)						x															
Fine particle size from soil mass movement source (ch. V) (tons)											x		x								
Coarse particle size from soil mass movement source (ch. V) (tons)											x	x									
Surface erosion (ch. IV) (tons)														x							
Bankful stream width (ft)																					x
Bankful surface water slope (ft/ft)																					x
Bankful depth (ft)																					x
Bankful discharge (cfs)																					x
Measured width from measured third order stream discharge (ft)																		x		x	
Measured depth from measured third order stream discharge (ft)																		x		x	
Measured surface water slope from measured third order stream discharge (ft/ft)																		x		x	
Predicted change in width with post-silvicultural activity																			x		
Predicted change in surface water slope with post-silvicultural activity																			x		

(1) baseline condition (pre-silvicultural activity)

(2) existing condition (pre-silvicultural activity)

(3) proposed condition (post-silvicultural activity).

Discussion: Distribution estimates of excess water both before and after silvicultural activity are required to determine changes in both suspended sediment and bedload discharge. If a particular short duration stormflow response is responsible for the majority of the sediment discharge in a particular reach, a shorter duration (less than 7-day) analysis will increase the sensitivity for flow related sediment transport calculations. Thus, the user may specify a local hydrologic evaluation, which is more accurate than the procedures recommended.

It may be necessary to determine the hydrologic effect of various activities on the rising and recession limbs of the hydrograph. If a hysteresis effect is prevalent, separate analyses may be made using the relationships established in step 3.

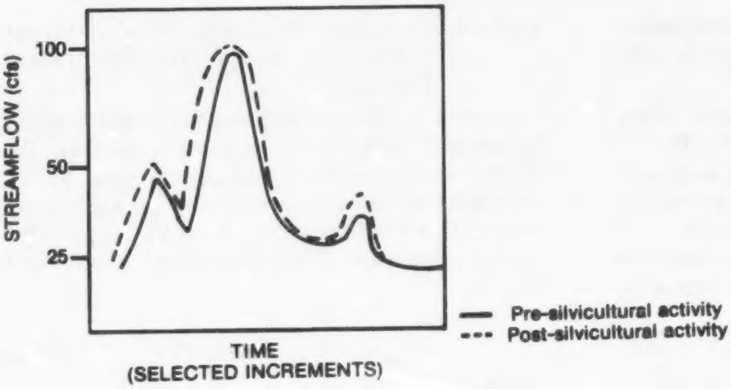


Figure VI.10a—Typical hydrograph.

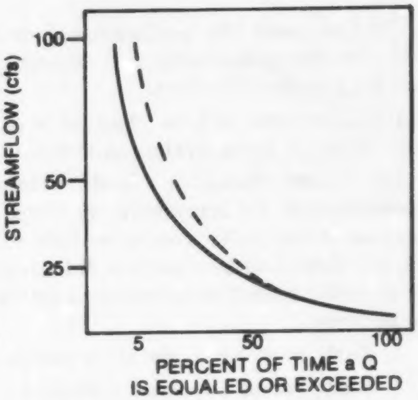


Figure VI.10b.—Flow duration curve.

Note: If silvicultural activity does not increase flow, the calculations involving post-activity flow related suspended and bedload increases would not be needed for the evaluation.

Suspended Sediment

Step 3. Establish Sediment Rating Curves and Determine Stream Channel Stability

Procedure: (a) Concurrently measure suspended sediment, and associated stream discharge over wide variations in flow conditions for a water year (fig. VI.11). After the data have been collected a regression analysis should be employed to calculate coefficient of determination and the log transformed regression equation of:

$$\log Y = b + n \log Q \qquad \text{(VI.1)}$$

where:

$\log Y$ = logarithm of suspended sediment concentration (mg/l)

b = constant representing intercept of the regression line

n = constant representing slope of the regression line

$\log Q$ = logarithm of stream discharge (cfs or m^3/sec)

The actual data points are plotted on log-log paper with suspended sediment in mg/l on the Y axis and stream discharge in cfs on the X axis. Using this data, coefficients for a regression equation of the form indicated in equation VI.1 are calculated. The regression line is then drawn on the figure (fig VI.12).

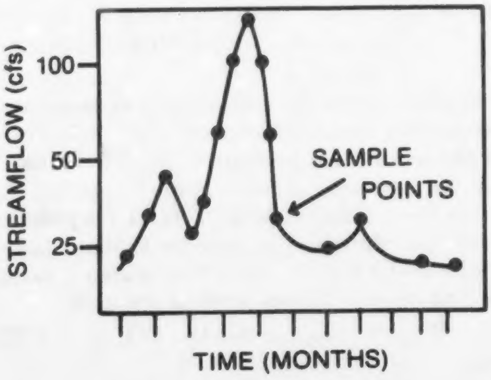


Figure VI.11.—Representative sediment sampling distribution.

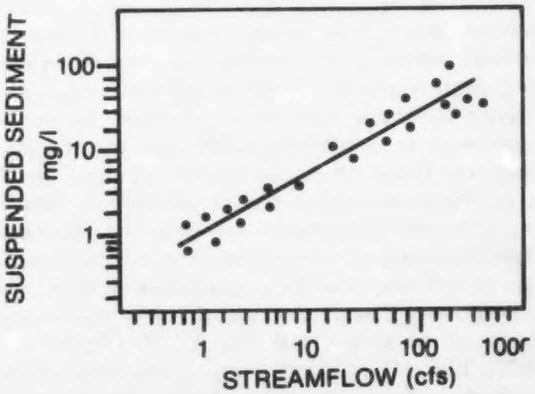


Figure VI.12.—Sediment rating curve.

(b) Calculate the coefficient of determination (r^2) for the relationship and identify variability (such as hysteresis effect).

(c) Determine stream channel stability rating for the reach being evaluated (Pfankuch 1975).

Discussion: Sampling should obtain sediment concentration for representative flows, as well as seasons where these concentrations expect to be varied. Sampling as a minimum for representative flow should reflect concentrations for the following conditions:

1. Early and/or low elevation snowmelt runoff;
2. Early versus late season stormflow runoff;
3. Rising stage for both stormflow and snowmelt runoff;
4. Recession stage for both stormflow and snowmelt runoff;
5. Bankful stage on higher peaks;
6. High elevation releases and/or snowmelt peaks;
7. Base flow;
8. Events which may affect the sediment rating curve, such as rain on snow events, short duration-high intensity storms, or long duration storms producing sustained high flows;
9. Disturbance factors influencing sediment supply, such as debris jams, changes in channel stability (sampled concurrently above and below to determine influence of stored sediment, etc.), road crossings or encroachments, and large areas of subdrainage hydrologically altered by vegetative modifications.

If significant differences in sediment concentration result from the rising versus falling limbs of the hydrograph or earlier storm peaks, these relationships should be kept separate and used in the calculation of both pre- and post-silvicultural activity streamflow effects to more accurately portray existing conditions. A more detailed hydrologic evaluation would increase the curve sensitivity for these conditions. Separate regression lines may be established and used for the appropriate flows when calculating pre- and post-silvicultural activity sediment discharge (steps 4 and 5) caused by increased flow only. This requires additional data on water yield to reflect the potential runoff response to a particular activity on various stormflow periods and rising versus falling limbs of the hydrograph (fig. VI.13) (Fredriksen 1977). The two sediment rating curves then can be applied to those respective portions of the post-silvicultural activity hydrograph (fig. VI.10a).

Step 4. Calculate Pre-Silvicultural Activity Potential Suspended Sediment Discharge

Procedure: From the pre-silvicultural activity hydrograph (baseline + existing condition, fig. VI.10a) and the sediment rating curve (fig. VI.12), determine sediment concentration for each 7-day average flow condition. Worksheet VI.1 is provided for this calculation. The formula used in worksheet VI.1 is:

$$S_{pre} = (Q_{pre})(C)(K)(T) \qquad (VI.2)$$

where:

S_{pre} = pre-silvicultural activity suspended sediment discharge (tons/yr)

C = concentration of suspended sediment (mg/l)

Q_{pre} = pre-silvicultural activity streamflow (cfs or m^3/sec)

K = conversion factor 0.0027 (.0864 if streamflow is in m^3/sec) (Guy and Norman 1970)

T = duration (days)

Calculation format is provided in worksheet VI.1, columns 2 to 4. Summarized sediment discharge increments (col. 4, wksht. VI.1) is transferred to worksheet VI.3, item A. To obtain values of C, use the pre-silvicultural activity 6- or 7-day average flow (fig. VI.10a); then utilizing figure VI.12, sediment rating curve, read vertically to the regression line, then horizontally where the Y axis indicates corresponding values of suspended sediment concentrations (C). This is done for each flow value of pre-activity discharge given a specified (6- or 7-day) duration. Worksheet VI.1 provides an accounting format for these calculations.

Step 5. Calculate Post-Silvicultural Activity Potential Suspended Sediment Discharge

Procedure: From the post-activity hydrograph or post-activity flow duration curve (fig. VI.10 a or b) and the sediment rating curve (fig. VI.12), determine the sediment concentration for each 7-day average flow condition. Worksheet VI.1 is provided for this calculation. The formula that is used in worksheet VI.1 is the same as that in step 4, except that post-activity values for flow are used.

$$S_{post} = (Q_{post})(C)(K)(T) \qquad (VI.3)$$

where:

S_{post} = post-activity suspended sediment discharge due to flow increase

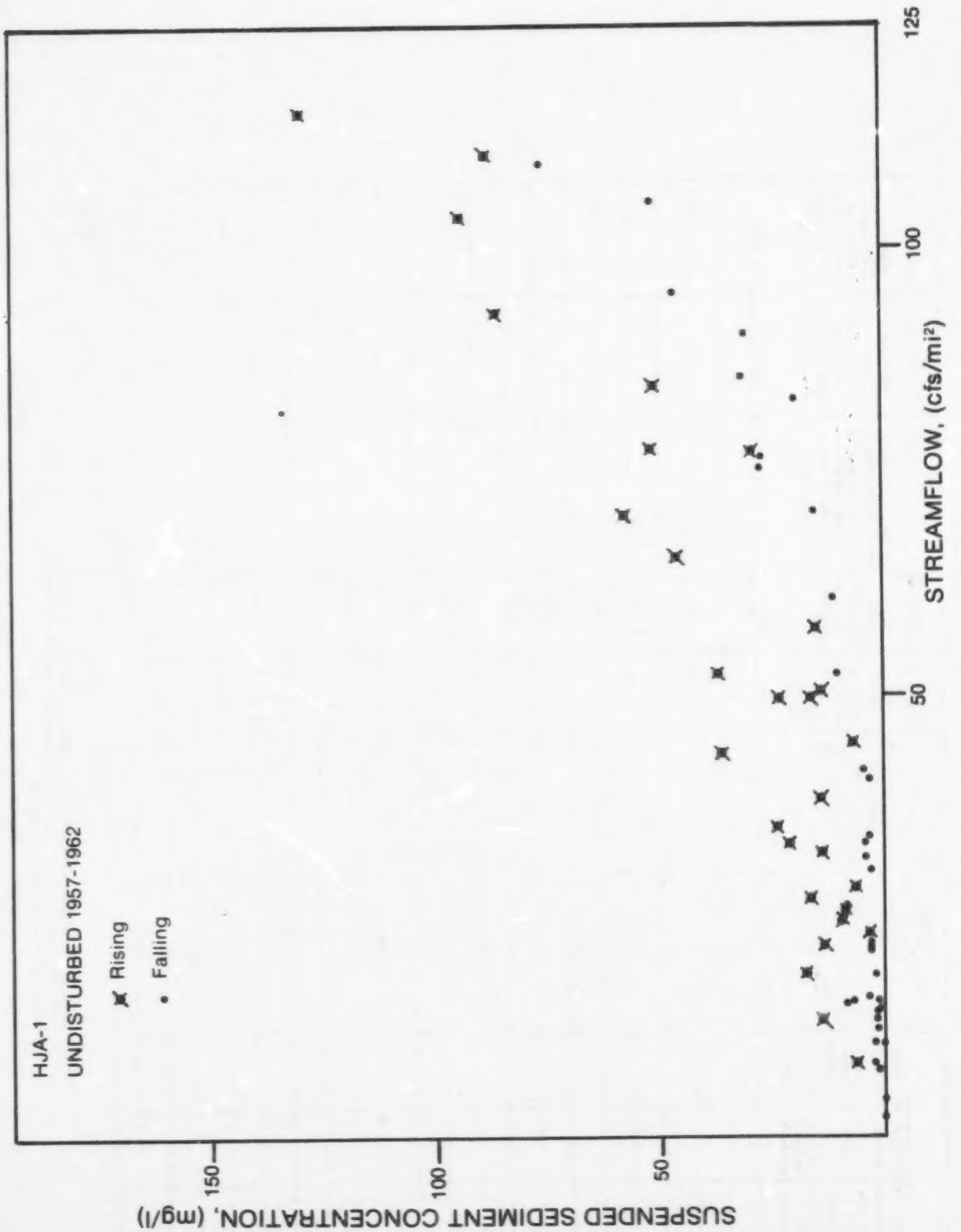


Figure VI.13—Sediment rating curve for H. J. Andrews Stream 1, showing variation in sediment concentration under rising versus falling limbs of the hydrograph. (Fredriksen 1977).

WORKSHEET VI.1

Suspended sediment quantification for ____________________

(1) Time Increment			(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(a) With hydrographs use date; with flow duration curves use $ of 365 days	(b) Number of days pre-silvicultural activity	(c) Number of days post-silvicultural activity	Pre-silvicultural activity flow (cfs)	Suspended sediment concentration (mg/l)	Total increment suspended sediment cols. (2) x (3) x (1.b) x .0027 (tons)	Post-silvicultural activity flow (cfs)	Suspended sediment concentration (mg/l)	Total increment post-silvicultural activity suspended sediment cols. (5) x (6) x (1.c) x .0027 (tons)	Maximum concentrations from selected water quality objective (mg/l)	Maximum sediment discharge cols. (2) x (8) x (1.b) x .0027 (tons)

(Totals are rounded to nearest tenth)

Total ________ tons/yr

Total ________ tons/yr

Total ________ tons/yr

Summary: Total pre-silvicultural activity suspended sediment discharge = ________
Total post-silvicultural activity suspended sediment discharge = ________
Total maximum sediment discharge = ________

Q_{post} = post-activity discharge (cfs)
C = concentration of suspended sediment (mg/l)
K = conversion factor 0.0027 (.0864 if streamflow is in m³/sec) (Guy and Norman 1970)
T = duration (days)

Summarize sediment discharge increments (col. 7, wksht. VI.1) and transfer total to worksheet VI.3, item B.

Discussion: The accuracy of this calculation is highly dependent on the hydrologic evaluation and on the observed variability in the sediment rating curves. A variability range may be presented as an option for tons/year of suspended sediment discharge. However, for comparative purposes, pre-activity values should be calculated similarly.

Step 6. Convert Suspended Sediment Limits in mg/l to tons/yr

Procedure: This calculation involves the same procedure used in step 4, except the suspended sediment concentrations (C_{MX}) are derived from various water quality objectives, expressed in mg/l. A conversion to comparable units in tons/year is needed to compare potentials for prescribed controls. Thus:

$$S_{MX} = (C_{MX})(Q_{pre})(T)(K) \qquad (VI.4)$$

where:

S_{MX} = maximum suspended sediment discharge (tons/yr)
C_{MX} = selected maximum suspended sediment concentrations (mg/l)
K = conversion factor 0.0027 (.0864 (metric tons) if streamflow is in m³/sec) (Guy and Normal 1970)
T = duration (days)

Discussion: The pre-silvicultural activity sediment rating curve is used to compare analysis output (tons/yr) to state standards which have allowable departures for suspended sediment concentration increases. Concentration values for the particular state standard are added to the existing concentrations for each 6- or 7-day flow increment (fig. VI.14).

If the water quality objective is to maintain equilibrium or stability of a stream system, a typical conversion would use stream channel stability ratings versus sediment rating curves. Exceedance levels may be inferred from the stability class lines using locally derived relationships (fig. VI.15). The major divisions above existing conditions of channel stability should be used. A conversion for pre-silvicultural activity flows from mg/l to tons provides an interpretation of the effects of introduced sediment (in tons) on channel stability.

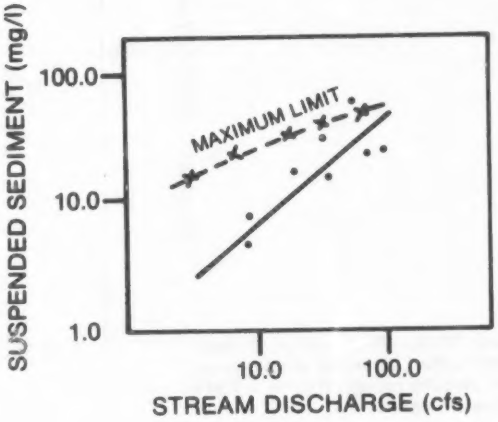


Figure VI.14—Use of a constant maximum limit for sediment concentration compared to sediment rating curve.

The calculation converts water quality objectives in mg/l to tons/year for comparative purposes only. It does not set objectives, but only provides a basis for comparison once water quality objectives are set: This allows comparison of suspended sediment discharge amount with these objections to determine when controls or mitigative measures may be applied. Columns 8 and 9 in worksheet VI.1 are provided for this analysis.

Bedload Calculation

Step 7. Establish Bedload Rating Curve

Procedure: Measure bedload transport (lb/sec or kg/sec) using the Helley-Smith bedload sampler concurrent with stream discharge (m³/sec or cfs) for representative flows.

The values of measured bedload transport in lb/sec or tons/day are evaluated against stream discharge in cfs in the log transformed regression equation:

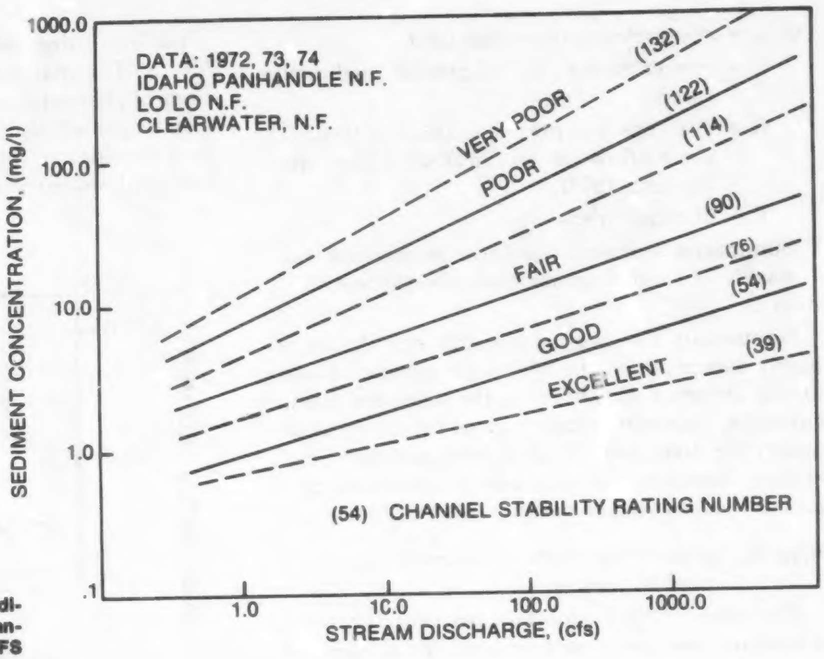


Figure VI.15.—Relationship of sediment rating curves to stream channel stability ratings, Region 1, USFS (Rosgen 1975b).

$$\log B_s = b + n \log Q \qquad \text{(VI.5)}$$

where:

$\log B_s$ = logarithm of bedload transport (lb/sec or tons/day)

b = constant representing intercept of the regression line

n = constant representing slope of the regression line

$\log Q$ = logarithm of stream discharge (cfs)

Regression analysis should be used to obtain the coefficient of determination (r^2) and the regression equation for the bedload rating curve.

Discussion: The same variables affecting the sampling design and representative flow monitoring apply to the bedload rating curves.

Step 8. Calculate Pre-Silvicultural Activity Potential Bedload Discharge

Procedure: Using bedload rating curve (step 7) and pre-activity excess water distribution (step 2) for 6- or 7-day time intervals, calculate annual bedload discharge using worksheet VI.2.

$$B_{pre} = (i_{b_{pre}})\,(T)\,(K) \qquad \text{(VI.6)}$$

where:

B_{pre} = pre-silvicultural activity bedload discharge (tons/year)

$i_{b_{pre}}$ = measured bedload transport rate (lb/sec) for pre-activity excess water

T = duration (days)

K = constant to convert lb/sec to tons/day

Discussion: The procedures used here are the same as in step 4, with the exception that bedload is used instead of suspended sediment. Enter the total of the pre-silvicultural activity potential bedload discharge as item E on worksheet VI.3.

Step 9. Calculate Total Pre-Silvicultural Activity Potential Sediment Discharge (Bedload and Suspended Load)

Add total pre-activity suspended sediment discharge (tons/year) (step 4) and total bedload sediment discharge (step 8), and enter on worksheet VI.3 as item K.

Step 10. Calculate Post-Silvicultural Activity Potential Bedload Discharge

Use worksheet VI.2, columns 1, 5, 6, and 7.

Procedure: Compute rates using post-silvicultural activity excess water (step 2) and bedload rating curves (step 7) using equation:

WORKSHEET VI.2

Bedload sediment quantification for ______________________

(1) Time increment			(2) Pre-silvicultural activity flow	(3) Bedload transport rate	(4) Total pre-silvicultural activity bedload discharge cols. (3) x (1.b)	(5) Post-silvicultural activity flow	(6) Bedload transport rate	(7) Post-silvicultural activity bedload discharge cols. (6) x (1.c)
(a) with hydrographs use date; with flow duration curves use % of 365 days	(b) Number of days pre-silvicultural activity	(c) Number of days post-silvicultural activity	Q_{pre} (cfs)	I_{bpre} (tons/day)	B_{pre}	Q_{post} (cfs)	I_{bpost} (tons/day)	B_{post}

(Totals are rounded to nearest tenth)

Total ________ tons/yr

Total ________ tons/yr

Summary: Total pre-silvicultural activity bedload discharge = ______________

Total post-silvicultural activity bedload discharge = ______________

WORKSHEET VI.3

Sediment prediction worksheet summary

Subdrainage name__________________________ Date of analysis__________

Suspended Sediment Discharge

A. Pre-silvicultural activity total potential suspended sediment discharge (total col. (4), wksht. VI.1) (tons/yr) __________

B. Post-silvicultural activity total potential suspended sediment discharge (total col. (7), wksht. VI.1) (due to streamflow increases) (tons/yr) __________

C. Maximum allowable potential suspended sediment discharge (total col. (9), wksht. VI.1) (tons/yr) __________

D. Potential introduced sediment sources: (delivered)

1. Surface erosion (tons/yr) __________
2. Soil mass movement (coarse) (tons/yr) __________
3. Median particle size (mm) __________
4. Soil mass movement--washload (silts and clays) (tons/yr) __________

Bedload Discharge (Due to increased streamflow)

E. Pre-silvicultural activity potential bedload discharge (tons/yr)__________

F. Post-silvicultural activity potential bedload discharge (due to increased streamflow) (tons/yr) __________

Total Sediment and Stream Channel Changes

G. Sum of post-silvicultural activity suspended sediment + bedload discharge (other than introduced sources) (tons/yr) __________ (sum B + F)

H. Sum of total introduced sediment (D) = (D.1 + D.2 + D.4) (tons/yr) __________

I. Total increases in potential suspended sediment discharge

1. (B + D.1 + D.4) - (A) (tons/yr) __________
2. Comparison to selected suspended sediment limits (I.1) - (C) (tons/yr) ± __________

WORKSHEET VI.3--continued

J. Changes in sediment transport and/or channel change potential (from introduced sources and direct channel impacts)

1. Total post-silvicultural activity soil mass movement sources (coarse size only) (tons/yr) ________

2. Total post-silvicultural soil mass movement sources (fine or washload only) (tons/yr) ________

3. Particle size (median size of coarse portion) (mm) ________

4. Post-silvicultural activity bedload transport (F) (tons/yr) ________

Potential for change (check appropriate blank below)

Stream deposition ____

Stream scour ____

No change ____

K. Total pre-silvicultural activity potential sediment discharge (bedload + suspended load) (tons/yr) ________ (sum A + E)

L. Total post-silvicultural activity potential sediment discharge (all sources + bedload and suspended load) (tons/yr) ________ (sum G + H)

M. Potential increase in total sediment discharge due to proposed activity (tons/yr) ________ (subtract L - K)

$$B_{post} = (i_{b_{post}})\,(T)\,(K) \qquad \text{(VI.7)}$$

where:

B_{post} = post-silvicultural activity bedload discharge (tons/year)

$i_{b_{post}}$ = bedload transport rate (lb/sec) for post-activity excess water

T = duration (days)

K = constant to convert lb/sec to tons/day

Discussion: The increase in bedload sediment discharge is a function of increased streamflow through vegetative alterations.

Total Sediment

Step 11. Obtain Introduced Sediment from Soil Mass Movement

Obtain total potential sediment delivered by soil mass movement processes in tons/year (ch. V). Add to total sediment discharge, all sources, step 16. Record on worksheet VI.3, lines D.2 and D.4.

Step 12. Obtain Total Coarse-Size Sediment from Soil Mass Movement

Obtain total potential introduced coarse-sized sediment delivered by soil mass movement processes. Record on worksheet VI.3, lines D.2 and J.1.

Procedure: Subtract the percentage of fines (silts and clays) from total delivered sediment to obtain the coarse fragment size (sands and larger) (Data input for step 20).

Discussion: This indicates only the potential of increased sediment available to a stream. Since sediment routing is not attempted with these procedures, it is not possible to determine the amount of coarse-sized soil mass movement material that would be available to the third order drainageway over various periods. A certain amount will go into temporary storage. A qualitative evaluation in step 21 may provide additional interpretations on stream channel impacts due to the change in sediment supply from this source.

Step 13. Determine Fine Size Volume from Soil Mass Movement

Procedure: Calculate percent by volume of soil mass movement material that is composed of the fine soil fraction, .0625 mm or smaller — silts and clays (washload). Compare output at step 16 — post-activity total suspended sediment discharge at the third order stream reach (step 15).

Step 14. Obtain Total Introduced Suspended Sediment (tons/yr) from Surface Erosion, Chapter IV

Procedure: Self-explanatory.

Discussion: Since the assumption is made that the delivered sediment from surface erosion is washload (silts and clays), then the total volume delivered would be evaluated at the third order reach. These data are used to compare introduced sediment to selected limits (step 15).

Step 15. Compare Post-Silvicultural Activity Total Potential Suspended Sediment (in Tons) to Selected Limits

Procedure: Add total of suspended sediment increases from:

1. Flow related increases (step 5)
2. Surface erosion source (step 14)
3. Soil mass movement, washload (step 13).

Subtract total of post-activity tons from allowable maximum sediment discharge (S_{MX}).

Discussion: Individual processes (surface erosion, soil mass movement, and streamflow) can be analyzed independent of each other to determine respective contributions. In this manner, controls which relate to specific processes may be properly recommended where applicable (tables II.2 to 14, ch. II).

Step 16. Post-Silvicultural Activity Total Potential Sediment Discharge—All Sources

Procedure: Total Sediment = Σ [output steps (5) (10) (11) and (14)] Add total of sediment discharge (in tons/yr) from:

1. Suspended sediment post-activity flow related increases (step 5)
2. Bedload post-activity flow related increases (step 10)
3. Soil mass movement volumes (step 11)
4. Surface erosion source (step 14).

Discussion: This calculation only evaluates potential changes in sediment availability within a third order watershed. It does not assume that all eroded material is routed to the third order reach.

Step 17. Increase in Total Potential Sediment Discharge From Silvicultural Activities

Procedure: Subtract total volume (tons/year) of pre-activity sediment discharge (step 9) from total post-activity sediment discharge (step 16).

Discussion: Although the data output represents a combined total of all sources, individual contributions may be evaluated where needed when considering management controls or mitigative measures.

Step 18. Collect Channel Geometry Data for Third Order Stream

Procedure: Measure surface water slope (ft/ft) on the stream reach where bedload data is collected. Also measure stream width for the various flows as measured in the establishment of the bedload rating curve.

Discussion: This information is necessary to establish a sediment transport rate-stream power relationship (step 20) for the third order watershed. It is also required to obtain changes in sediment transport rate on first to third order stream channels caused by activities which affect either surface water slope or bankful stream width (step 19).

Step 19. Evaluate Post-Silvicultural Activity Channel Impacts

Procedure: Determine post-activity changes influencing stream power calculations by surface water slope or bankful stream width. Using post-activity bankful width and/or surface water slope, revised stream power calculations and resultant revised bedload transport rates for impacted stream reaches (step 20) may be obtained.

Discussion: Changes in stream width and/or surface water slope can be obtained by field determinations based on the results of similar activities on stream reaches (i.e., upstream versus downstream measured surface water slope associated with debris jams indicates relative change anticipated with similar activities).

Step 20. Establish Bedload Sediment Transport Rate-Stream Power Relationship for Third Order Stream Reach

Procedure: Using width (step 2), water surface slope and actual bedload transport data (step 7), establish the relationship:

$$\log i_b = a + b \log_\omega \qquad \text{(VI.8)}$$

where:

$\log i_b$ = logarithm of measured bedload transport rate (lb/sec/ft)

a = intercept of regression line

b = slope representing regression line

$\log_\omega$ = logarithm stream power (lb/sec/ft)

$$\text{stream power} = [62.4 \text{ lbs ft}^3 \times \text{surface water slope (ft/ft)} \times \text{stream discharge (cfs)}] \div \text{stream width}$$

Use worksheet VI.4 for this calculation.

Determine the median sediment size in transport from seiving the bedload sampler catch (D_{50}). If the sizes in transport vary as stream power increases, analyze data separately to develop various particle size stream power requirements as shown in figure VI.8 (Leopold and Emmett 1976).

Discussion: The purpose of this calculation is to develop a local relationship of bedload transport rate-stream power to predict potential stream channel adjustments. If it is desired to complete the same analysis on first and second order streams, it will be necessary to obtain site specific information for the respective reaches. This is required because a flow evaluation is not provided for the first and second order streams.

The data required are:

1. Measure surface water slope (from riffle to riffle).
2. Measure bankful stage width (using bankful stage as described by Williams (1977)).
3. Measure bankful stage depth.

The reliability of the data will be reduced by extrapolating bedload transport rate data to the first and second order streams. Extrapolation is less reliable because actual changes in bedload particle size in transport and corresponding stream powers are not measured. The processes affecting transport rate, however, are the same; therefore, the reduced reliability may be acceptable. If it is not acceptable, measurement of the first and second order reaches is recommended to more accurately develop the bedload transport rate-stream power relationships.

Step 21. Qualitative Determinations of Channel Change Potential Based on Introduced Sediment from Soil Mass Movement and Channel Impacts (wksht. VI.5)

Procedure:

a. Determine change in surface water slope.

b. Determine change in bankful stream width.

c. Determine change in bankful stream depth.

d. Obtain volume of introduced sediment from soil mass movement source (step 12).

WORKSHEET VI.4

Bedload transport-stream power relationship for ____________________

(1) Water surface slope S (ft/ft)	(2) Constant (62.4) K (lb/ft^3)	(3) Measured stream discharge Q (cfs)	(4) Stream width W (ft)	(5) Stream power $\frac{\text{cols. (1)} \times \text{(2)} \times \text{(3)}}{\text{col. (4)}}$ (ft/lb/sec)	(6) Measured bedload transport rate i_b (tons/day)	(7) Convert bedload transport from tons/day to ft/lb/sec, [col. (6) × 2,000] ÷86,400 × col.(4) i_b (ft/lb/sec)

Complete the following analysis:

a. Plot value of stream power (ω), column (5) on X-axis and values of bedload transport rate [i_b, column (7)], on double log graph paper.

b. Calculate regression equation and coefficient of determination (r^2).

WORKSHEET VI.5

Computations for step 21 ____________________
(stream name)

Changes in bedload transport-stream power due to channel impacts

1. Potential changes in channel dimensions

   a. Bankful stage width (W_{pre}) ______ (W_{post}) ______

   b. Bankful stage depth (D_{pre}) ______ (D_{post}) ______

   c. Water surface slope (S_{pre}) ______ (S_{post}) ______

   d. Bankful discharge (Q_{Bpre}) ______ (Q_{Bpost}) ______

where: $Q_{Bpre} = 0.366 + 1.33 \log A_{pre} + 0.05 \log S_{pre} - 0.056 (\log S_{pre})^2$

where: A = cross-sectional area (a) × (b) ______

S = water surface slope (c) ______

Calculate Q_{Bpost} using post-silvicultural A and S

$$Q_{Bpost} = 0.366 + 1.33 \log A_{post} + 0.05 \log S_{post} - 0.056 (\log S_{post})^2$$

2.a. Pre-silvicultural activity stream power calculation (ω_{pre})

$$\omega_{pre} = \frac{\underset{(1.c)}{S_{pre}} \times \underset{(K)}{62.4} \times \underset{(1.d)}{Q_{Bpre}}}{\underset{(1.a)}{W_{pre}}} = \_\_\_\_\_\_\_\_\_\_$$

2.b. Post-silvicultural activity stream power calculation (ω_{post})

$$\omega_{post} = \frac{\underset{(1.c)}{S_{post}} \times \underset{(K)}{62.4} \times \underset{(1.d)}{Q_{Bpost}}}{\underset{(1.a)}{W_{post}}} = \_\_\_\_\_\_\_\_\_\_$$

3. Calculate post-silvicultural activity bedload transport rate at bankful discharge, using post-silvicultural activity stream power

e. Determine median particle size (mm) of delivered soil mass movement material.

f. Calculate bankful discharge on impacted stream reach.

Procedure for determining bankful discharge:

(1) Determine upper limits of the active floodplain (Williams 1977).
(2) Measure bankful stream width.
(3) Measure bankful stream depth.
(4) Calculate area (width × depth).
(5) Measure water surface slope.
(6) Solve for bankful discharge, Q in equation.

$$\log Q = 0.366 + 1.33 \log A + 0.005 \log S - 0.056 (\log S)^2 \qquad \text{(VI.9)}$$

(Riggs 1976)

where:

Q = discharge (cfs)
A = area (ft^2)
S = water surface slope (dimensionless)

g. Extrapolate bedload transport rate-stream power relationships established on third order reach to the reach being evaluated.

h. Calculate maximum bedload transport rate using bankful discharge stream power. Compare to total introduced sediment from soil mass movement source. If introduced sediment exceeds transport rate at bankful discharge, sediment deposition may be expected in the stream reach.

i. Calculate changes in sediment transport rate caused by a reduction in surface water slope from debris jams. If revised stream power calculation creates a reduction in sediment transport rate, sediment deposition in the channel may be expected. This assumes there is no reduction in sediment availability within the watershed upstream of the reach being evaluated.

Discussion: These qualitative evaluations indicate relative potential for channel change, namely deposition or stream channel aggradation (longer than 1 year of influence). A numerical indicator is used for this potential change. Long-term monitoring is necessary to provide quantitative prediction and time series recovery of stream channels in the interim. These calculations are recommended when considering management controls and/or mitigative measures.

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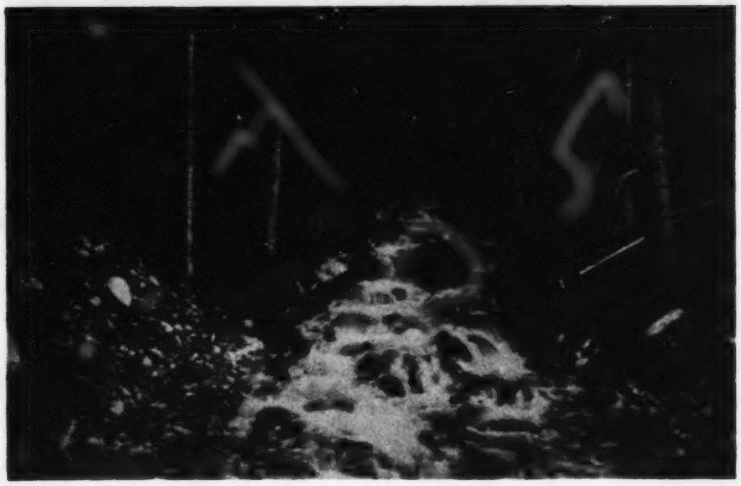
APPENDIX VI.A

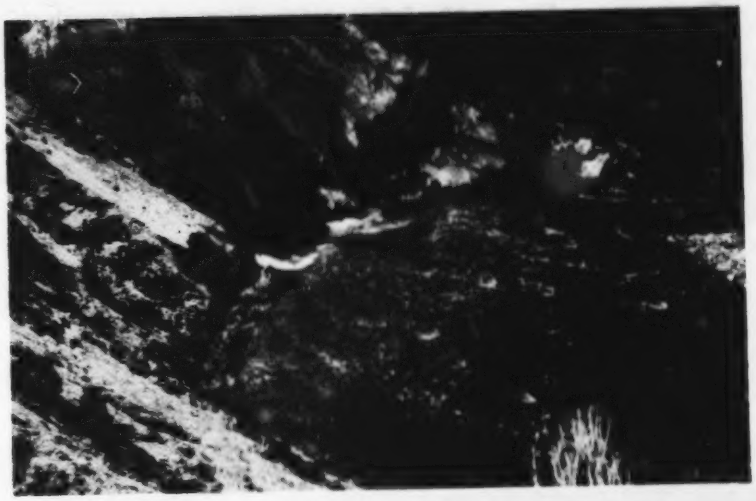
EXAMPLES OF CHANNEL STABILITY RATINGS

Figure VI.A.1.—Stream channels indicative of a stable channel due to resistant bed and bank materials.

Figure VI.A.2.—Stream channels indicative of a stable channel due to resistant bed and bank materials.

Figures VI.A.3. - VI.A.5.—Stream channels indicative of stable channel due to resistant bed and bank materials.





Figures VI.A.6. - VI.A.8.—Highly unstable channels or channels having poor stability ratings are generally associated with easily detached bank and bed material where channel erosion is significant.

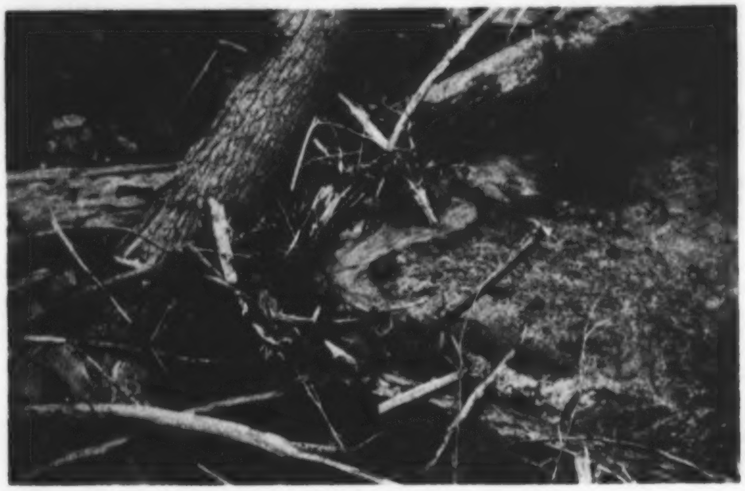


Figure VI.A.9.—Stability and associated sediment supply affected by organic debris which increase sediment storage with resultant channel changes and bank erosion.

Figure VI.A.10.—Stability and associated sediment supply affected by organic debris. Excessive deposition and associated increased sediment storage occurs with resultant channel changes, bank erosion and other changes.

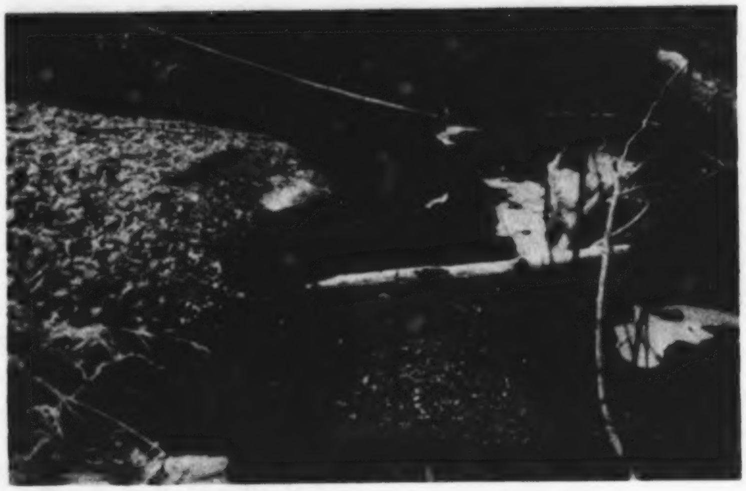


Figure VI.A.11.—Changes in stability due to increases in sediment supply from road crossings. Such introduced sediment sources can exceed the carrying capacity of the stream.

Figure VI.A.12.—Soil mass movement, due to debris avalanche processes, deliver excessive amounts of sediment to the stream. This will often change the stream stability and associated supply-energy relationship.

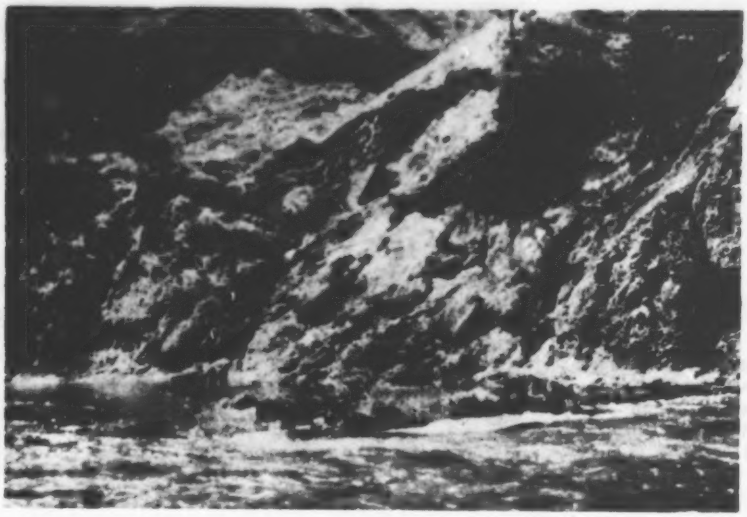


Figure VI.A.13.—Soil mass movement, due to slump-earthflow processes, deliver excessive amounts of sediment to the stream. This will often change the stream stability and associated supply-energy relationships.

APPENDIX VI.B

RELATIONSHIPS BETWEEN SEDIMENT RATING CURVES AND CHANNEL STABILITY

To provide a link between the morphological characteristics of stream channels, as determined by the channel stability rating procedure (Pfankuch 1975), and sediment rating curves, regression analyses were made on over 80 streams in northern and central Idaho and northwestern Montana involving sediment rating curves and channel stability ratings. The relationship is shown in figure VI.B.1 (Rosgen 1975b). Correlation coefficients (R^2) were 0.94 for the "good and excellent" (38 to 76), 0.91 for the "fair channel stability" (77 to 114), and 0.94 for the "poor or unstable" channels (115 to 132). A covariance analysis was conducted (Bernath 1977) indicating highly significant correlations when comparing stability ratings for various populations. The F values were highly significant at the 0.01 level.

Since then, work conducted in California has shown widespread application of this technique where 27 streams with sediment rating curves were evaluated using the same stability procedures (fig. VI.B.2). Concentrations for the same flows are considerably higher in the California streams, but the stability evaluation provides a comparison of the different regression constants and stability ratings within a given locale using the same procedures (Laven 1977). Similar relationships are indicated in figure VI.B.3 where sediment rating curves were related to stability ratings in Colorado (Rosgen 1977b).

Additional validation of this procedure has been conducted in Wyoming, Oregon, New Mexico, North Carolina, New Hampshire, Vermont, and Virginia; tentative results indicate that this procedure applies to many areas other than where it was developed (Rosgen 1977a). This success is due to the application of the procedures (process related) rather than extrapolation of actual curves or regression equations from region to region. The use of this procedure demands the development of

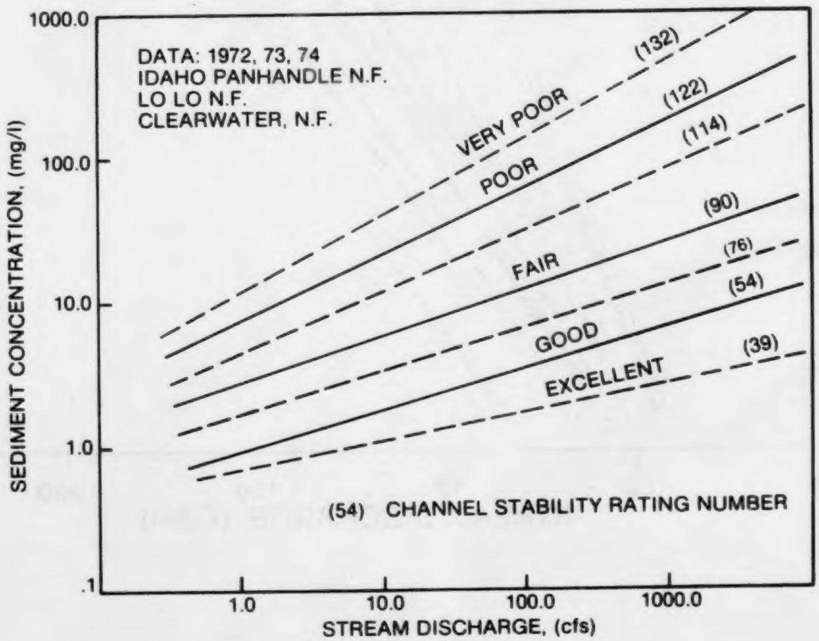


Figure VI.B.1.—Relationship of sediment rating curves to stream channel stability ratings, Region 1, USFS (Rosgen 1975b).

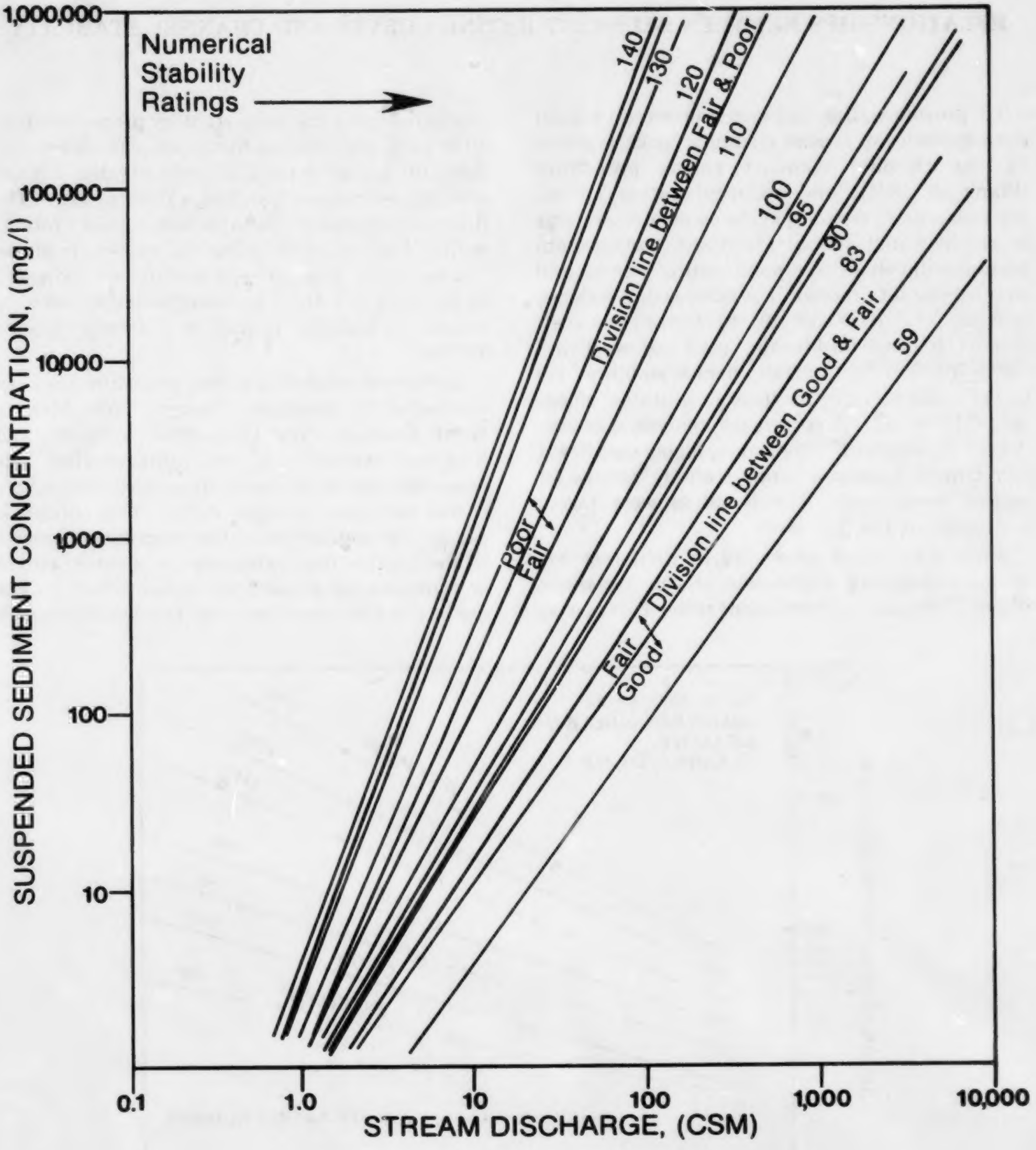


Figure VI.B.2.—Relationship of channel stability ratings to sediment rating curves in the Redwood Creek drainage, California (Laven 1977).

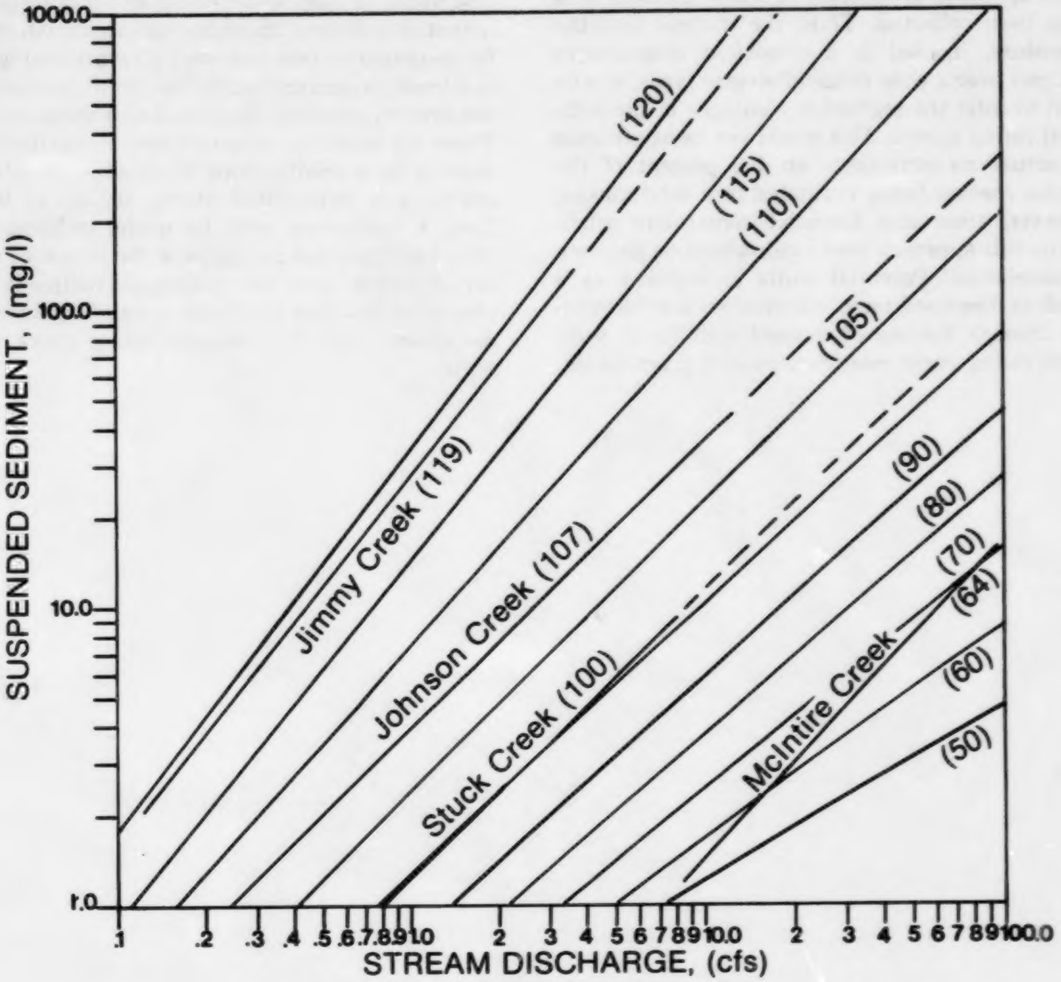


Figure VI.B.3.—Relationship of channel stability ratings to sediment rating curves for streams in the central Rocky Mountain region. (Rosgen 1977a).

local curves based on actual sediment rating curve data. Once this step has been completed, information can be obtained from many miles of stream reach upstream or adjacent to where sediment data have been collected. Thus, the channel stability procedure, if used in a consistent comparative analysis over a wide range of stream types, can be used to infer the regression constants of the sediment rating curves. This would not be as accurate as actual measurements on 100 percent of the stream reaches being evaluated in a subdrainage; however, time and financial constraints might justify this approach once local validation has been accomplished. Potential shifts in stability as a result of direct sediment introduction may be inferred through the use of channel stability — sediment rating curve relationships in a given locale.

The "stability threshold" of streams can be interpreted as the lines between the major stability classes as shown in figure VI.B.1. This interpretation would be used where either actual or proposed potential sediment discharge, as calculated, could be compared to that sediment discharge using the maximum concentrations for the stability class and pre-activity seasonal distribution of excess water. These are based on measured data in the development of these relationships. If potential introduced sediment is anticipated during periods of lower flow, a comparison may be made, utilizing less than bankful stage discharge. If the increased supply is higher than the maximum sediment discharge for that flow condition, a stability change or associated shift in sediment rating curve may occur.

APPENDIX VI.C

TIME SERIES ANALYSIS-RECOVERY PROCEDURE

It is often desirable to determine the duration of sediment impacts in a stream system. Little work is available which sets time series recovery for sediment rating curves, although observations indicate relative rates of recovery which vary considerably between streams. It is not possible to predict this recovery at this time; however, a procedure can be applied once channel morphological data are collected and pre- and post-sediment rating curves are measured.

Time recovery for streams using the sediment rating curve approach may be shown as:

A. Pre-silvicultural activity sediment rating curve or baseline characterization relationship.

$$\log Y = b + n \log Q \qquad \text{(VI.1)}$$

where:

$\log Y$ = logarithm of pre-silvicultural activity suspended sediment concentration (mg/l)

b = pre-silvicultural activity regression constant expressing intercept of the regression line

$\log Q$ = logarithm of pre-silvicultural activity instantaneous stream discharge in cubic feet per second

n = pre-silvicultural activity regression exponent expressing slope of the regression line

B. Post-silvicultural activity relationship expressing the time series recovery.

$$Y_t^* = (b^* e^{-Yt})\,(Q)^{(n^* e^{-zt})} \qquad \text{(VI.C.1)}$$

where:

Y_t^* = post-silvicultural activity sediment concentration (mg/l) for a specified time following activity

b = post-silvicultural activity regression constant expressing intercept of the regression line

e = base of natural logarithms

$-Y$ = negative exponent expressing relationship of recovery of intercept

Q = post-silvicultural activity instantaneous stream discharge (ft^3 per section)

n^* = post-silvicultural activity regression exponent expressing slope of the regression line

$-z$ = negative exponent expressing recovery relationship of slope

t = time (years) since initial disturbance

The relationships can be used to determine the rate of decline of the sediment rating curve following disturbance. Data requirements include the availability of measured pre- and post-silvicultural activity rating curves on streams to calculated values of Y^t and zt for similar stream systems for various years.

Models which determine potential "time-trends" in erosion and sedimentation are published and have been used in the central and northern Rocky Mountains (Megahan 1974 and Leaf 1974). Sediment reduction resulting from roads was primarily addressed where vegetative recovery greatly reduced delivery to a stream.

Before this stream channel-time recovery approach can be applied, stream morphological data will be needed prior to and following treatments of various streams to determine what variables are responsible for the shift in the sediment rating curve. Before adjusted values of Y^t and zt are available, qualitative broad interpretations of recovery are presently all that can be applied.

Chapter VII

TEMPERATURE

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INTRODUCTION

The temperature of small headwater streams of forested areas is an important determinant of overall water quality. Temperature acts not only to control the metabolic rates and functions of aquatic biota but also serves to maintain community structure. Change in temperature affects species composition. Microorganisms at the base of the food chain may be directly affected which eventually will affect all higher organisms in the food pyramid.

Water temperature changes may be either beneficial or detrimental. A moderate temperature increase in streams that are cooler than optimum could increase productivity and have a beneficial effect on the aquatic environment. However streams having temperatures that approach critical threshold limits during the summer months may exceed these limits and have a detrimental effect on aquatic organisms. In addition, winter stream temperatures may be decreased by canopy removal. Exposure of the water surfaces could result in greater convectional heat loss from the water to the atmosphere.

Increased stream temperature affects fish populations in several ways, many of which are detrimental. High temperature kills fish directly, decreases the dissolved oxygen (DO) concentration, increases the susceptibility of fish to disease by increasing bacteriological activity, affects availability of food, and alters feeding activities of fish. Increased stream temperatures indirectly alter community composition by providing a habitat favorable to warm water species.

There are numerous publications that relate the impacts of timber harvesting to stream temperature and subsequent effects on fish populations (Eschner and Larmoyeux 1963, Brown and others 1971). Their studies show that removal of shading vegetation as a result of harvesting can increase stream temperatures because of increased exposure to solar radiation. The magnitude of the impact is a function of the amount of critical canopy removed, duration of exposure, streambed material, area exposed, stream discharge, initial water temperature, and groundwater influx (Stone 1973). Cloud cover is not considered since maximum potential daily temperature increase is being evaluated.

THE PROCEDURE

SOURCES OF ENERGY INFLUX CONTRIBUTING TO INCREASED WATER TEMPERATURE

Removal of streamside vegetation that provides shade to the water surface can cause significant stream temperature increases. Several sources of energy influx interact and contribute to the net change in temperature of a stream. This relationship may be expressed in the following energy budget equation (Brown 1969 and Lee 1977):

$$\Delta H = NR \pm A_d \pm C_d \pm E \pm C_v \qquad \text{(VII.1)}$$

where:

ΔH = energy manifested by a change in water temperature,

NR = net radiation (incoming-outgoing all wave radiation),

A_d = advective energy exchange due to precipitation, ground water, or tributary flows,

C_d = conductive energy exchange between streambed material and water,

E = evaporation and condensation, and

C_v = convective energy exchange at water surface, atmosphere interface.

Net Radiation, NR

Brown (1969, 1972) has shown that 95 percent of the energy influx of small, completely exposed streams can be accounted for by net radiation. Net solar radiation is defined as the algebraic sum of incident and reflected sun and sky shortwave radiation, incident and reflected atmospheric longwave radiation, and longwave radiation emitted by the water body. It is the principal energy influx controlling the maximum temperature increase in exposed streams. Solar radiation itself is not controllable, but the amount of water surface exposed can be controlled. Shading by vegetation limits the amount of solar radiation received by the water course (Reifsnyder and Lull 1965).

Advective Energy Flux, A_d

Advective energy flux is the transmission of heat by horizontal currents through a fluid such as the atmosphere or water. In specific situations these significantly modify temperature increases; for example, advective inputs by groundwater normally decrease maximum summer temperatures. Groundwater temperatures generally approach the average annual air temperature, and so are generally cooler than surface water during the summer months. The magnitude of this reduction will depend upon the temperature difference between the surface and the groundwater, and upon the volume of groundwater entering the stream as compared to the volume of streamflow in the surface water.

Advective inputs by tributaries may either increase or decrease maximum receiving stream temperature depending upon whether the tributary stream contains warmer or cooler water. Like groundwater, the magnitude of the change in water temperature of a receiving stream will be determined by the temperature and volume of the tributary flow compared to the temperature and volume of the receiving stream. Temperature changes associated with ground water or tributary flows can be expressed mathematically by a simple proportion:

$$\Delta T_a = \frac{D_1T_1 + D_2T_2}{D_1 + D_2} \qquad \text{(VII.2)}$$

where:

ΔT_a = change in water temperature, receiving stream,

D_1 = discharge, receiving stream,

T_1 = temperature, receiving stream,

D_2 = discharge, tributary stream, and

T_2 = temperature, tributary stream.

Conductive Energy Exchange Between Streambed Material And Water, C_d

In a conductive energy exchange heat is transferred through matter by kinetic energy (energy of motion) from particle to particle. Stream temperatures will vary with streambed composition. Generally, bedrock streambeds will act as heat sinks with resulting conductive losses of energy from the water body to the rock (Brown 1972). Gravel, sand, and fine materials comprising streambeds have interparticulate voids that minimize conductive heat losses. The color of the rock also influences the magnitude of the conductive heat loss. Darker rock will absorb more energy than lighter rock.

Evaporation And Condensation, E

Evaporation is the principal process by which heat is lost from the water surface. It occurs whenever the saturation vapor pressure of the water is greater than the ambient vapor pressure. This happens during the summer when the water is cooler than the air and, in particular, during the midday period. Heat loss from the water via evaporation is only a fraction of the radiant energy influx and does not significantly alter the maximum temperature increases in most small streams where silvicultural activities are conducted. However, as the water temperature increases to equilibrium, evaporation increases and heat loss from the water due to evaporation may exceed the heat influx from net radiation.

Convective Energy Exchange, C_v

Convective energy exchange occurs whenever there is a temperature gradient between the water mass and air mass. The energy exchange may be positive or negative depending upon whether the air is warmer or cooler than the water. During critical periods of maximum water temperature, the air mass will usually be warmer than the water and will reinforce the radiant energy influx to increase water temperature.

BROWN'S MODEL: ESTIMATING MAXIMUM POTENTIAL TEMPERATURE INCREASE

Brown (1970, 1972) developed a model for predicting the maximum potential daily change in temperature resulting from the complete exposure of a section of stream channel to direct solar radiation using the energy budget approach. Field measurements showed that net thermal radiation accounted for over 95 percent of the energy influx to exposed water courses (Brown 1969). (Validation of Brown's model is discussed in appendix VII.A.) The energy term in the initial model was simplified based upon the assumption that net solar radiation is the only source of energy to an exposed stream. The simplified model is:

$$\Delta T = \frac{AH}{Q} 0.000267 \qquad \text{(VII.3)}$$

where:

ΔT = maximum potential daily temperature increases expected from exposing a section of stream to direct solar radiation, in degrees Fahrenheit.

A = surface area in square feet of stream exposed to direct solar radiation,

Q = discharge of the stream, in ft^3/sec

H = incident heat load (net solar radiation) received by the exposed water surface in BTU/ft^2-min, and

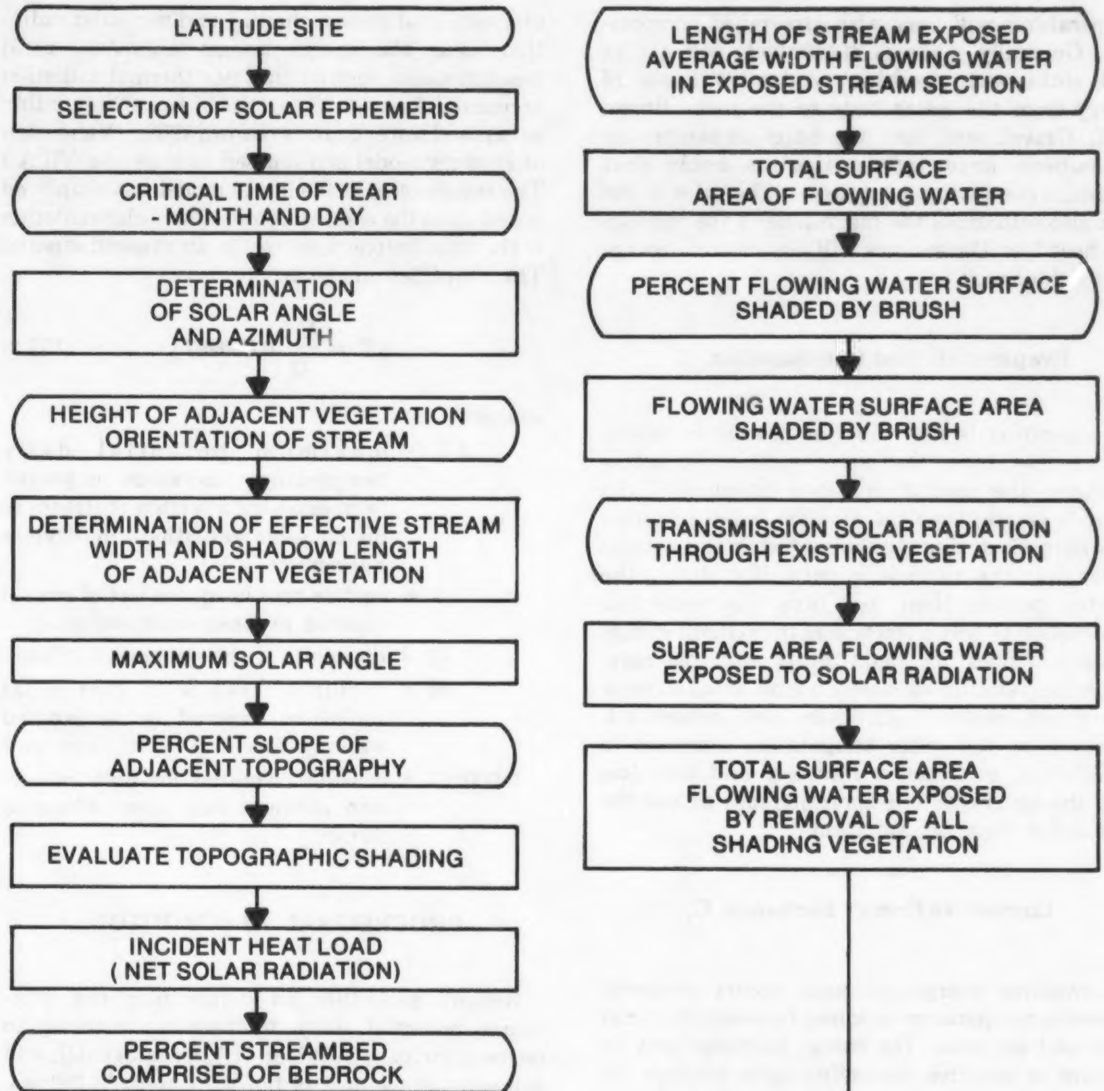
0.000267 = constant required for unit conversion converts flow from ft^3/sec to lb/min.

PROCEDURAL DESCRIPTION

Brown's procedure for determining the maximum potential daily temperature increase in terms of incident heat load (H), discharge (Q), and exposed surface area of flowing water (A) follows. These descriptive paragraphs correspond with the procedural flow chart organization in figure VII.1.

Determination Of Incident Heat Load, H

The incident heat load (net solar radiation), H, received by a water surface is determined by (1) the maximum solar angle of the sun; (2) the length of time a given volume of water will be exposed to solar radiation; (3) the amount of bedrock in the stream; and (4) the amount of vegetative and topographic shading of the water surface. The following steps are involved in computing the incident heat load.


LATITUDE SITE
SELECTION OF SOLAR EPHEMERIS
CRITICAL TIME OF YEAR - MONTH AND DAY
DETERMINATION OF SOLAR ANGLE AND AZIMUTH
HEIGHT OF ADJACENT VEGETATION ORIENTATION OF STREAM
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MAXIMUM SOLAR ANGLE
PERCENT SLOPE OF ADJACENT TOPOGRAPHY
EVALUATE TOPOGRAPHIC SHADING
INCIDENT HEAT LOAD (NET SOLAR RADIATION)
PERCENT STREAMBED COMPRISED OF BEDROCK
ADJUSTED NET SOLAR RADIATION FOR BEDROCK STREAMBEDS
LENGTH OF STREAM EXPOSED AVERAGE WIDTH FLOWING WATER IN EXPOSED STREAM SECTION
TOTAL SURFACE AREA OF FLOWING WATER
PERCENT FLOWING WATER SURFACE SHADED BY BRUSH
FLOWING WATER SURFACE AREA SHADED BY BRUSH
TRANSMISSION SOLAR RADIATION THROUGH EXISTING VEGETATION
SURFACE AREA FLOWING WATER EXPOSED TO SOLAR RADIATION
TOTAL SURFACE AREA FLOWING WATER EXPOSED BY REMOVAL OF ALL SHADING VEGETATION
DISCHARGE
MAXIMUM POTENTIAL DAILY TEMPERATURE INCREASE
DECISION POINT
PROCEDURAL STEP COMPUTATION OR EVALUATION
DATA INPUT
ANALYSIS OUTPUT

Figure VII.1. Flow diagram showing the sequence of steps and data required for evaluating the maximum potential daily temperature increase in degrees Fahrenheit.

LATITUDE SITE

The latitude of the site must be known. Exact latitudinal location to the nearest minute or second is not required, as the difference in net radiation over two to three degrees of latitude is not significant for this analysis procedure.

SELECTION OF SOLAR EPHEMERIS

A solar ephemeris is defined as a table or figure that gives the sun's location, angle and azimuth, for each day. Four solar emphemerides are provided (figs. VII.2 - VII.5), representing four latitudes — 35° N, 40° N, 45° N, and 50° N. Select one solar ephemeris most appropriate for the latitude of the site of the silvicultural activity. For example, if the latitude of the site is 40-½° N, the solar ephemeris for 40° N would be utilized.

CRITICAL TIME OF YEAR — MONTH AND DAY

Select the time of year when stream temperature increases are critical. This normally occurs during the summer months when the stream is lowest and heat influx is greatest.

Using the previous example, locate the declination in the solar ephemeris for 40° N latitude (fig. VII.3) that corresponds to the date when maximum water temperature increase is anticipated. If the critical period is the second week in July, the declination would be +21-½°. Interpolate between given declination lines for dates other than those given. For the declination of the second week in July, interpolate between declinations +23°27′ and +20° (June 22 and July 24, respectively).

DETERMINATION OF SOLAR ANGLE AND AZIMUTH

Maximum radiation will occur during the midday hours on clear days. The heat load received by the stream depends on the solar angle and azimuth. As the solar angle increases, more radiant energy reaches the water surface and there is a reduction of reflected radiation. Brown (1970) developed curves for net incoming (shortwave and diffuse) solar radiation (BTU/ft^2–min) based upon solar angle and reflectivity. He determined that heat might be added to a stream by incoming longwave radiation; however, back radiation from the water was about the same magnitude. Therefore, the net change in stream heat from longwave radiation is assumed to be zero. Solar angle and azimuth, of course, depend upon season, time of day, and latitude.

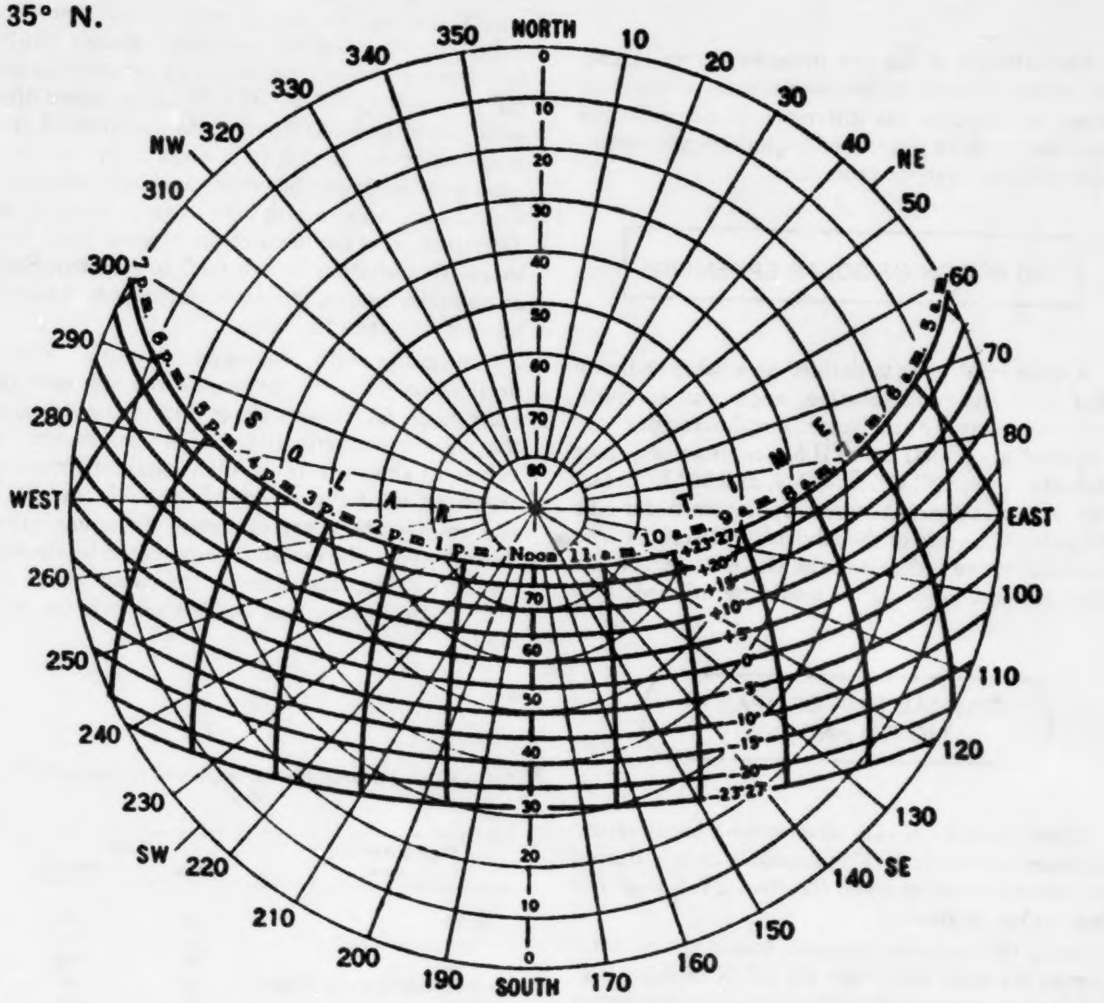
Continuing with the same example, with a declination +21-½°, determine the azimuth and solar angle for various times during the day from the solar ephemeris (fig. VII.6) and record the values as shown in table VII.1. Azimuth readings are found along the outside of the circle (fig. VII.6) and are given for every 10 degrees. Solar angle (i.e., degrees above the horizon) is indicated by the concentric circles. The time is indicated above the +23°27′ declination line and is given in hours, solar time.

Table VII.1.—Variation of solar angle and azimuth with time of day[1]

Daylight savings time	Solar	
	angle	azimuth
12:30	70	155
1:00 (solar noon)	72	180
1:30	70	205
2:10 (oriented with stream)	68	225
2:30	65	235
2:45	60	240
3:10	55	245

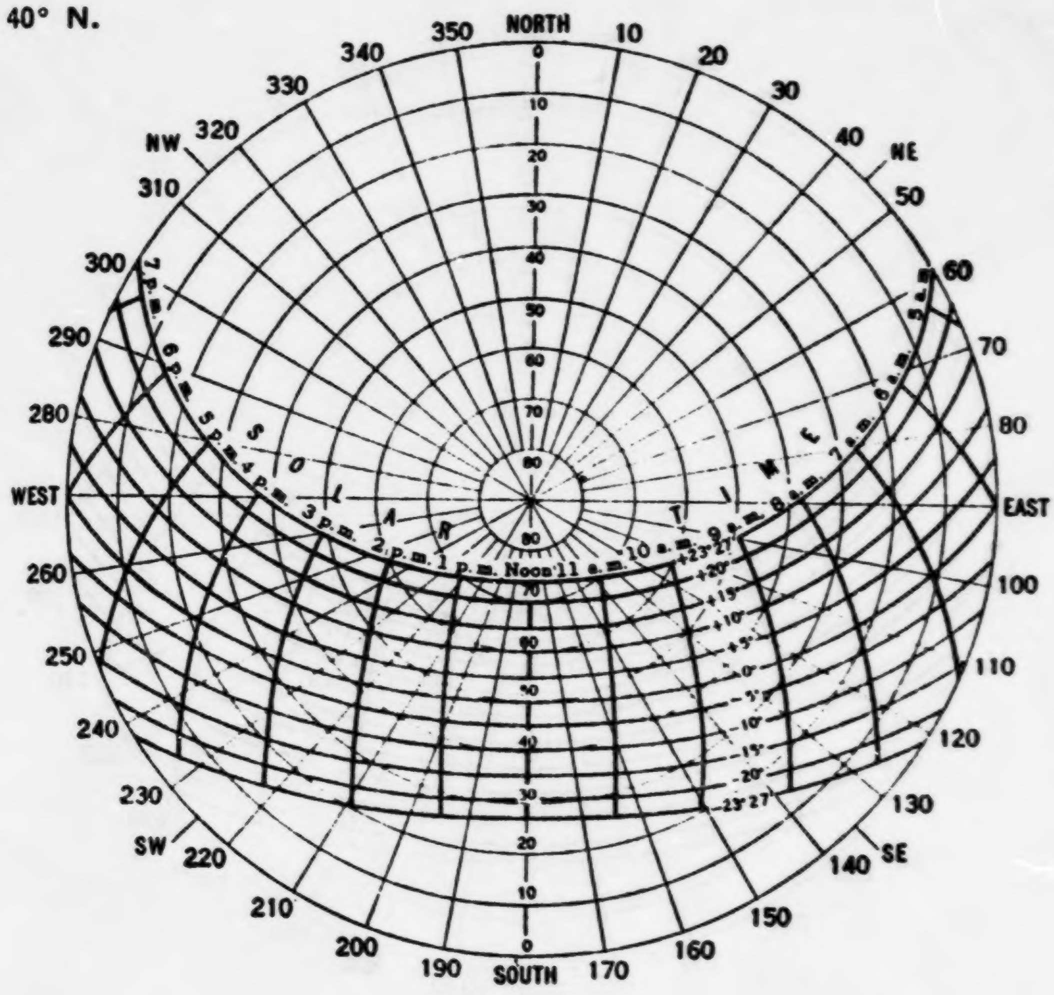
[1] See "Chapter VIII: Procedural Examples" for worksheets corresponding to data appearing in this chapter's tables and figures.

To determine the solar angle and azimuth that would occur at 12:30 p.m. daylight savings time: follow along the +21-½° declination line that is interpolated between the +20° and +23°27′ line. Locate the point that is equal distance between the 11:00 a.m. (12:00 a.m. daylight savings time) and noon (1:00 p.m. daylight savings time) time interval. This point represents 12:30 daylight savings time.



Declination	Approx. dates
+23° 27′	June 22
+20°	May 21, July 24
+15°	May 1, Aug. 12
+10°	Apr. 16, Aug. 28
+ 5°	Apr. 3, Sept. 10
0°	Mar. 21, Sept. 23
— 5°	Mar. 8, Oct. 6
−10°	Feb. 23, Oct. 20
−15°	Feb. 9, Nov. 3
−20°	Jan. 21, Nov. 22
−23° 27′	Dec. 22

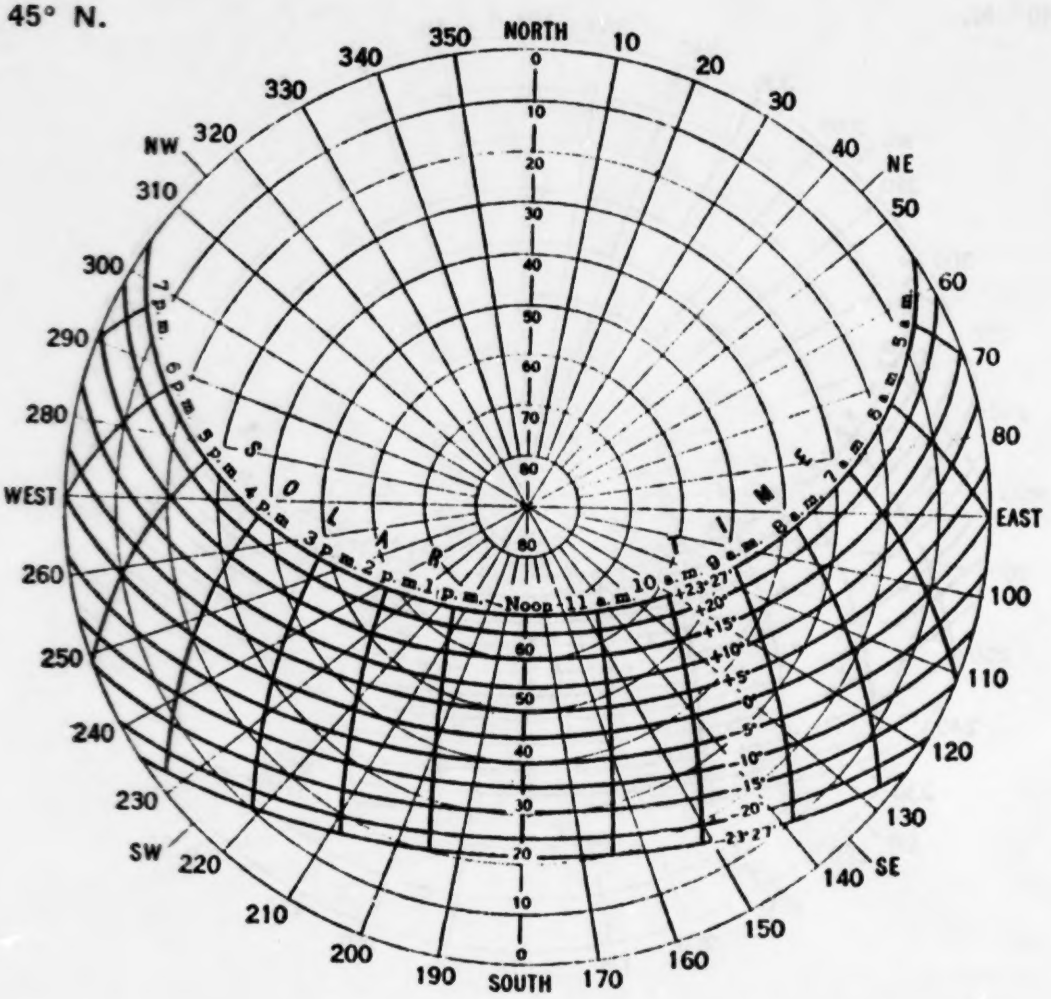
Figure VII.2.—Solar ephemeris for 35° N latitude.



Declination	Approx. dates
+23° 27′	June 22
+20°	May 21, July 24
+15°	May 1, Aug. 12
+10°	Apr. 16, Aug. 28
+ 5°	Apr. 3, Sept. 10
0°	Mar. 21, Sept. 23
— 5°	Mar. 8, Oct. 6
—10°	Feb. 23, Oct. 20
—15°	Feb. 9, Nov. 3
—20°	Jan. 21, Nov. 22
—23° 27′	Dec. 22

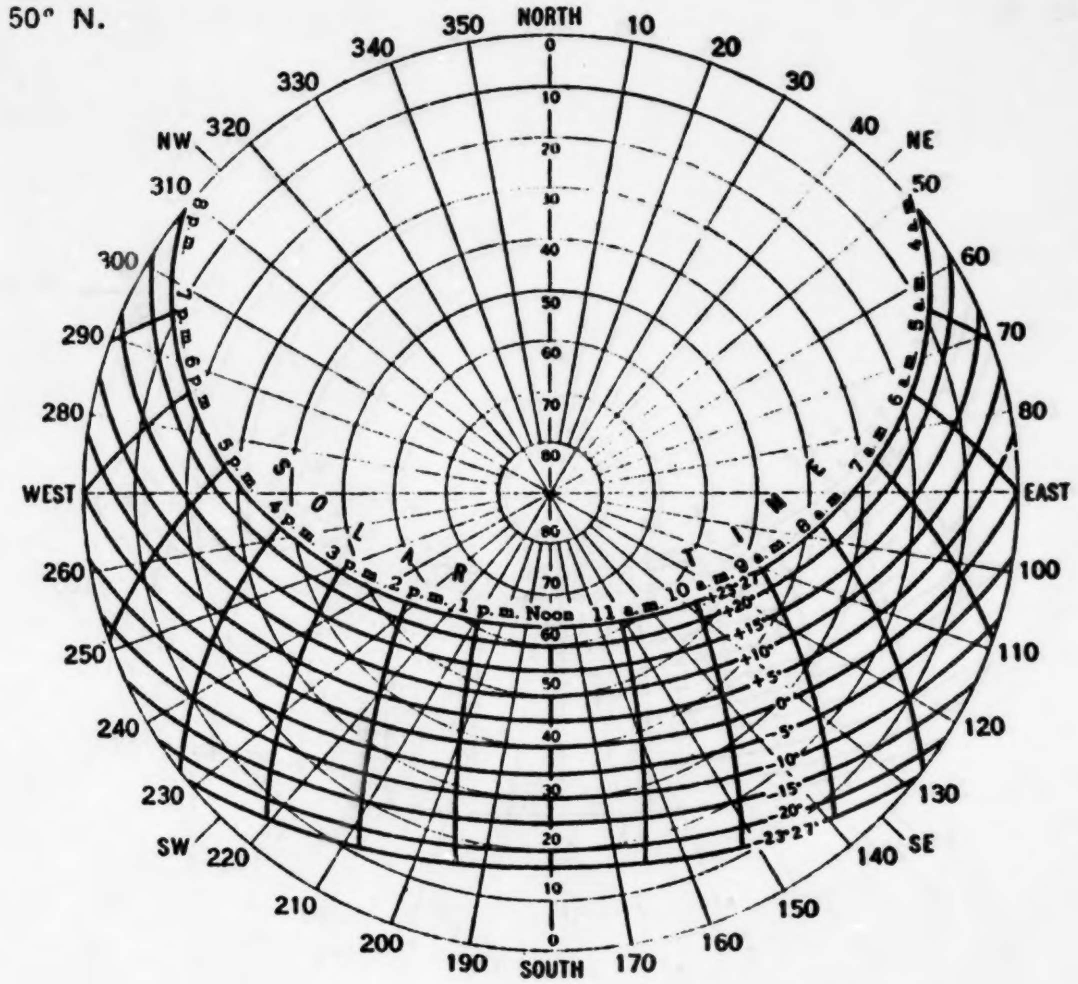
Figure VII.3.—Solar ephemeris for 40° N latitude.

45° N.



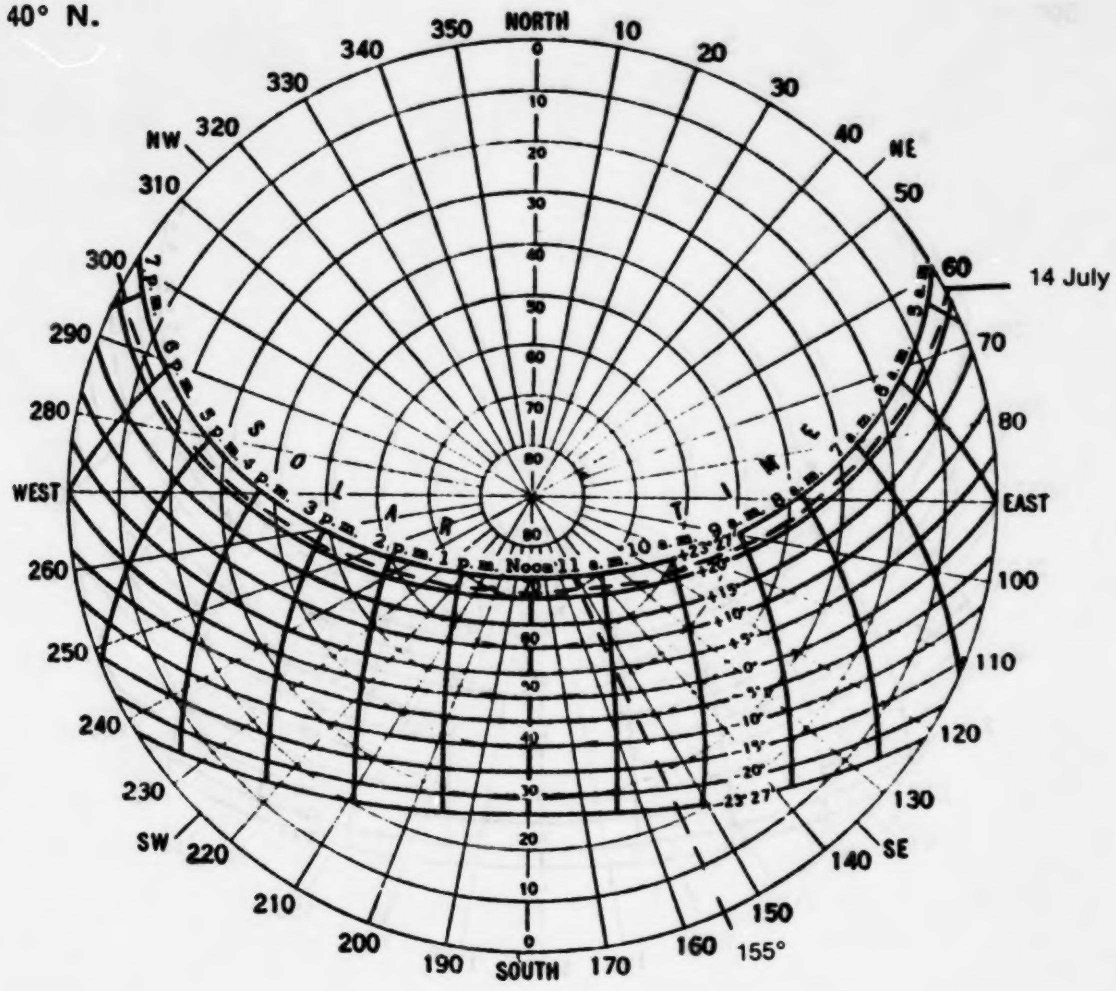
Declination	Approx. dates
+23° 27′	June 22
+20°	May 21, July 24
+15°	May 1, Aug. 12
+10°	Apr. 16, Aug. 28
+ 5°	Apr. 3, Sept. 10
0°	Mar. 21, Sept. 23
— 5°	Mar. 8, Oct. 6
—10°	Feb. 23, Oct. 20
—15°	Feb. 9, Nov. 3
—20°	Jan. 21, Nov. 22
—23° 27′	Dec. 22

Figure VII.4.—Solar ephemeris for 45° N latitude.



Declination	Approx. dates
+23° 27′	June 22
+20°	May 21, July 24
+15°	May 1, Aug. 12
+10°	Apr. 16, Aug. 28
+ 5°	Apr. 3, Sept. 10
0°	Mar. 21, Sept. 23
− 5°	Mar. 8, Oct. 6
−10°	Feb. 23, Oct. 20
−15°	Feb. 9, Nov. 3
−20°	Jan. 21, Nov. 22
−23° 27′	Dec. 22

Figure VII.5.—Solar ephemeris for 50° N latitude.



	Declination	Approx. dates
	+23° 27′	June 22
14 July →	+20°	May 21, July 24
	+15°	May 1, Aug. 12
	+10°	Apr. 16, Aug. 28
	+ 5°	Apr. 3, Sept. 10
	0°	Mar. 21, Sept. 23
	− 5°	Mar. 8, Oct. 6
	−10°	Feb. 23, Oct. 20
	−15°	Feb. 9, Nov. 3
	−20°	Jan. 21, Nov. 22
	−23° 27′	Dec. 22

Figure VII.6.—Use of the solar ephemeris given the following illustrative data: latitude of 40-½° N, second week in July, and 12:30 p.m. daylight savings time.

The solar angle is determined by noting where the point established above (12:30 p.m. with a declination of +21-½°) occurs in respect to the solar angle lines present on figure VII.6. The solar angle lines are represented as concentric circles and range from 90° at the center to 0° at the periphery. The point established above falls on the 70° line; therefore, the solar angle is equal to 70°.

The solar azimuth is determined by noting where the point established above occurs in respect to the solar azimuth lines that radiate out from the center of the circle. The point falls midway between the 150° and 160° lines; therefore, the solar azimuth equals 155°.

More points should be selected about the midday period when solar radiation is at the greatest intensity as opposed to the early morning and/or late afternoon when solar radiation is less.

HEIGHT OF ADJACENT VEGETATION ORIENTATION OF STREAM

The height of vegetation adjacent to the stream effects the shading of the stream. Taller vegetation casts longer shadows and so can be further from the stream and still provide shade. The orientation of the stream azimuth in respect to the sun also determines the length of shadow. For a more detailed discussion of these relationships, refer to appendix VII.B.

DETERMINATION OF STREAM EFFECTIVE WIDTH AND SHADOW LENGTH OF ADJACENT VEGETATION

Evaluate the orientation of the sun (i.e., solar angle and azimuth determined previously, table VII.1), with the stream and determine what vegetation exists that shades the stream. To do this, compare stream effective width with shadow length. Determine the maximum solar angle (i.e., maximum radiation influx to stream) that will occur when the stream is exposed due to the silvicultural activity.

Assuming a stream azimuth of 225° and a height of 70 feet for vegetation adjacent to the stream, the following numerical computations illustrate how stream effective width and shadow length can be evaluated.

The direction the shadows fall across the stream will determine effective width of the stream (for a discussion of effective width, see appendix VII.B, "Streamside Shading").

Effective width is computed using the following formula:

$$\text{EW} = \frac{\text{measured average stream width}}{\text{sine}\,|\,\text{azimuth stream - azimuth sun}\,|} \qquad \text{(VII.4)}$$

The azimuth of the particular stream used for this illustration is 225°. This value (EW) varies depending on the time of day. For example, at 12:30 p.m. (table VII.1), EW would be equal to:

$$\text{EW} = \frac{1.5\text{ ft}}{\text{sine}\,|\,225° - 155°\,|} = 1.6\text{ ft}$$

The absolute value of azimuth of the stream less azimuth of the sun must be less than a 90° angle. Should the difference exceed 90°, subtract this absolute value from 180° to obtain the correct acute angle. The sine is then taken of this computed acute angle.

Shadow length (S) is computed using the formula:

$$\text{S} = \frac{\text{height vegetation}}{\text{tangent solar angle}} \qquad \text{(VII.5)}$$

For example, at 12:30 p.m., S would be equal to:

$$\text{S} = \frac{70\text{ ft}}{\text{tangent }(70°)} = 25.5\text{ ft}$$

Note, the only periods of the day that should be considered are those times when existing vegetation that will be eliminated by the silvicultural operation effectively shades the stream; i.e., when the shadow length extends onto some portion of the stream.

MAXIMUM SOLAR ANGLE

In the illustration used previously, the existing trees scheduled to be cut do provide shade to the stream. The only time of the day when the existing trees do not shade the stream occurs about 2:10 p.m. when the stream's effective width is infinity

Table VII.2.—Computation of stream's effective width (EW) and vegetative shadow length (S) based upon stream azimuth, solar azimuth, and solar angle

Daylight savings time	Solar angle	Solar azimuth	Effective width (EW = 1.5/sine 225-Solar azimuth)	Shadow length (S=70/tangent Solar angle)
	(°)		(ft)	(ft)
12:30	70	155	1.6	25.4
1:00	72	180	2.1	22.7
1:30	70	205	4.4	25.5
2:10	68	225	(infinity)	28.2
2:30	65	235	8.6	32.6
2:45	60	240	5.8	40.4
3:10	55	245	4.4	49.0

(sun is oriented with the stream) and the shadow length is only 28.2 feet (table VII.2). Therefore, removal of this vegetation would result in exposure of the water surface to increased solar radiation.

The proposed silvicultural operation would have the maximum impact on water temperature at 1:00 p.m. (solar noon) when the solar angle and radiation are greatest and when existing vegetation presently providing shade is removed. Therefore, the maximum solar angle would be 72°.

PERCENT SLOPE OF ADJACENT TOPOGRAPHY

The percent slope of the adjacent topography must be measured or estimated.

EVALUATE TOPOGRAPHIC SHADING

Topographic shading should be evaluated to determine if the water course would be shaded by topographic features. For topographic shading to be present, the percent slope of the ground must exceed the percent slope of the solar angle (i.e., tangent solar angle).

If the slope of the topography adjacent to the stream is 30 percent and table VII.2 gives the solar angle as 72° or 308 percent, topographic shading is not possible due to the angle of the sun and relatively gentle topographic relief.

INCIDENT HEAT LOAD (NET SOLAR RADIATION)

Given a specific site, the rate of incoming radiation is constantly changing. To determine the approximate heat load for the model, the length of time a given volume of water will be exposed to direct solar radiation also must be determined. Travel time of the stream can be found by measuring any of the following: average stream velocity using a current meter (ft/sec); empirical relationships using channel slope data; and/or dye tracing. The net solar radiation must be averaged for the time that the water will be exposed. This is accomplished by identifying or interpolating the appropriate midday solar angle curve and locating on the time axis the period of day that the stream will be exposed (fig. VII.7).

The radiation value occurring at the midpoint of the proposed period can normally be used as the average net radiation value. However, when the travel time is several hours and the exposed period goes from midmorning to early afternoon (for example, 9 a.m. to 1 p.m.), it may be necessary to consider the change in slope of the curve and to select a net radiation value more representative for the period rather than the midpoint. However, it should be noted that this model is for stream reaches less than 2,000 feet in length; travel time will normally not exceed 2 hours and generally will be less than 1 hour, thereby eliminating the need to determine an average net radiation value.

Estimate the incident heat load for the site (fig. VII.7). Continuing with the previous example:

1. Use the maximum solar angle determined previously (72°).
2. In figure VII.8, interpolate between the 70° and 80° curve to obtain the 72° values.
3. Determine the critical time period (1:00 p.m. in this example).
4. Find the average H value. Travel time through the exposed section of stream channel is only 0.3 hour; therefore, it is not necessary to find an average H value. From figure VII.8, with a 72° midday angle, the H value for 1:00 p.m. is approximately 4.7 BTU/ft²-min; if we had used the solar ephemeris for 45° N latitude, the H value would have been 4.5 BTU/ft²-min. Figure VII.8 illustrates the procedure used to obtain H in this example.

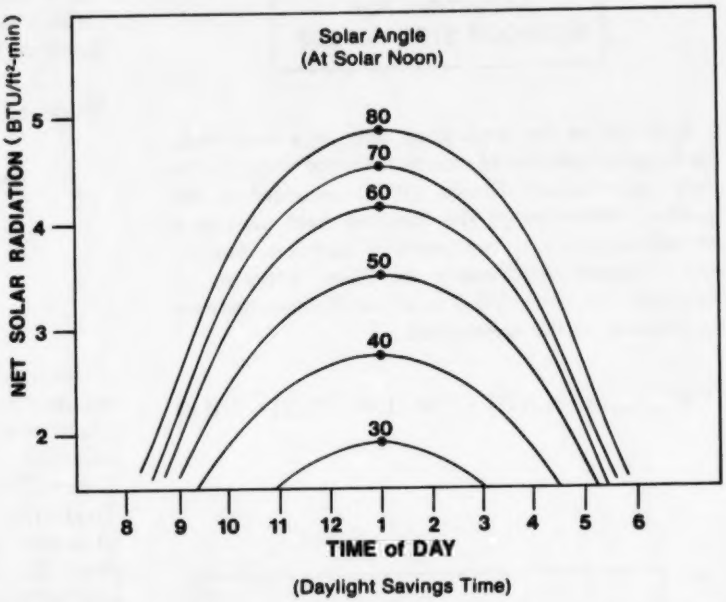


Figure VII.7.—Hourly values (BTU/ft²-min) for net solar radiation above water surfaces on clear days between latitudes 30° N and 50° N for several solar paths (Brown 1970).

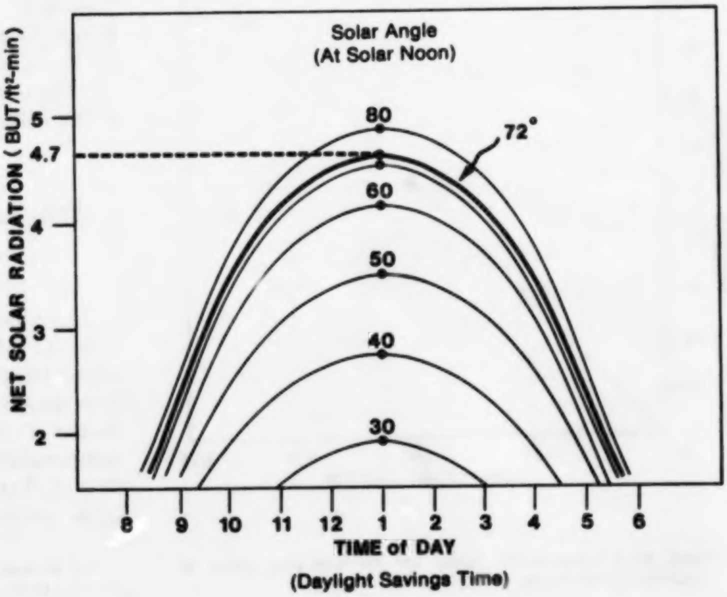


Figure VII.8.—Determination of net hourly solar radiation using noon angle of 72°. H is 4.7 BTU/ft²-min.

PERCENT STREAMBED COMPRISED OF BEDROCK

The percentage of streambed comprised of bedrock must be measured or estimated.

ADJUSTED NET SOLAR RADIATION FOR BEDROCK STREAMBEDS

Bedrock in the streambed acts as a heat sink, and conductive loss of energy from the water to the rock may occur. Brown (1972) recorded a 20-percent reduction of the incident heat load in a streambed entirely composed of bedrock. Assuming a linear relationship for lesser exposure of bedrock, use figure VII.9 to adjust H when bedrock is exposed in the streambed.

$$H_{adjusted} = [\%\,WH] + [\%B\,(1.00-C)\,H] \quad \text{(VII.6)}$$

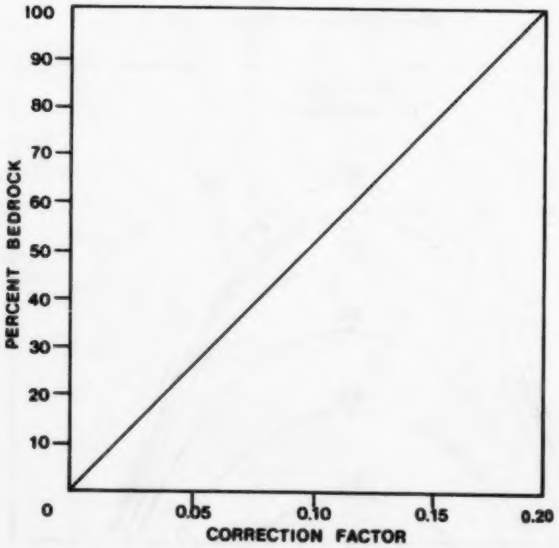


Figure VII.9.—Correction factor for the heat-sink effect of bedrock streambeds.

where:

W = percent streambed without bedrock[1] (e.g., 0.10),

H = unadjusted heat load (e.g., 4.7 BTU/ft^2-min with a solar ephemeris for 40° N latitude),

B = percent streambed with rock[1] (e.g., 0.90), and

C = correction factor[1] (e.g., 0.18).

C is obtained from figure VII.9. In the example, bedrock comprises 90 percent of the streambed; therefore H should be reduced by 18 percent.

$$H_{adjusted} = 0.10(4.7) + 0.90\,(1.00 - 0.18)\,4.7 = 3.94$$

Determination Of Discharge, Q

DISCHARGE

Discharge, that takes place during the critical summer period following silvicultural activities, when maximum water temperature may be anticipated, represents the flowing portion of the stream. This value should reflect any changes in discharge quantity and timing due to the silvicultural operation. "Chapter III: Hydrology" presents a discussion of a procedure and methodology for deriving these values. Discharge should be measured during the critical summer period prior to the proposed silvicultural activity. Any adjustments in discharge due to the silvicultural activity can then be made on this previously measured value.

Determination Of Exposed Surface Area Of Flowing Water, A

The exposed surface area of a stream is that portion of the flowing water affected by the silvicultural operation. Large pools with little or no flow do not significantly influence temperature increase of the flowing water. Brown (1972) found no temperature gradient in small pools in the direction of flow and only a small (0.2° C) gradient in large pools. The lack of complete mixing in the pools limits the transfer of heat (i.e., absorbed solar radiation) from the stagnant water in the pool to the flowing water. If the total surface area of pools is considered in determining stream surface area exposed, the predicted potential temperature increase will be inaccurate; and if more than one pool is present in the reach, the magnitude of error is increased even more. Dye can be used, if necessary, to determine the surface area of a pool that should be used in predicting temperature change.

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[1] *All percent values used in equation VII.6 should be in decimal form.*

Furthermore, the surface area of flowing water exposed by removal of vegetation must be adjusted to account for the surface exposure prior to the removal of the vegetation. Riparian vegetation and timber do not normally shade a stream so completely as to preclude the transmission of all solar radiation to the water surface. For example, a western coniferous stand with 400 square feet of basal area/acre may allow 5 to 15 percent of the solar radiation to penetrate (Reifsnyder and Lull 1965).

The following steps are involved in computing the exposed surface area, A.

LENGTH OF STREAM EXPOSED AVERAGE WIDTH FLOWING WATER IN EXPOSED STREAM SECTION

The length of stream that will be exposed by the silvicultural activity is measured or estimated. The average width of flowing water in this exposed section of stream is measured or estimated during the time of year when stream temperature is critical. Accuracy of these measurements or estimates is critical as the accuracy of the analysis is dependent upon this information (see app. VII.A, "Validation of Brown's Model").

TOTAL SURFACE AREA OF FLOWING WATER

The length of stream exposed, multiplied by the average width of flowing water, gives surface area.

For example, a stream with a length of 530 feet and an average width of flowing water of 1.5 feet has a total surface area of flowing water of 795 square feet.

$$\begin{aligned} A_{total} &= LW \qquad \text{(VII.7a)} \\ &= 530\ \text{ft} \times 1.5\ \text{ft} \\ &= 795\ \text{ft}^2 \end{aligned}$$

PERCENT FLOWING WATER SURFACE SHADED BY BRUSH

The percent shade provided by riparian brush and shrubs is estimated by field observation. Again, this estimate should be made during the time of year when stream temperature is critical. For the example discussed here, it was estimated that 15 percent of the flowing water surface was shaded.

FLOWING WATER SURFACE AREA SHADED BY BRUSH

The combination of shade provided by brush and tree canopy will generally prevent most of the net solar radiation from reaching the water surface. The surface area shaded by brush is therefore determined.

In this example, with 15 percent of the flowing water shaded during the critical period, surface area shaded by brush would be estimated at 120 square feet.

$$\begin{aligned} A_{shade\,brush} &= LW\ (\%\ \text{stream shaded by brush only}) \qquad \text{(VII.7b)} \\ &= 530\ \text{ft} \times 1.5\ \text{ft} \times 15\% \\ &= 120\ \text{ft}^2 \end{aligned}$$

TRANSMISSION SOLAR RADIATION THROUGH EXISTING VEGETATION

The solar radiation passing through the existing crown canopy must be measured or estimated. Refer to appendix VII.B for a discussion of how this might be measured and appendix VII.D for tabular displays of the relationship between stand density and transmission of solar radiation.

SURFACE AREA FLOWING WATER EXPOSED TO SOLAR RADIATION

Using surface area exposed under current vegetative canopy cover, correct for transmission of light through the existing stand that has a percent crown closure. Whenever possible, use only angular canopy density values (see "Angular Canopy Density" in app. VII.C). If only vertical crown closure values are available, estimate percent transmission of solar radiation. Values for these estimates may be obtained from Technical Bulletin 1334, pages 72-76 (Reifsnyder and Lull 1965). Assuming a crown closure of 65 percent, figure VII.10 shows that approximately 8 percent of the solar radiation will be transmitted through the canopy and reach the stream.

$$\begin{aligned} A_{\text{presently exposed}} &= (A_{\text{total}} - A_{\text{shade brush}}) \\ &\quad (\%\text{ transmission through existing vegetation}) \qquad \text{(VII.7c)} \\ &= (795\ \text{ft}^2 - 120\ \text{ft}^2) \times 8\% \\ &= 54\ \text{ft}^2 \end{aligned}$$

The flowing water, therefore, has approximately 54 square feet exposed to solar radiation.

TOTAL SURFACE AREA FLOWING WATER EXPOSED BY REMOVAL OF ALL SHADING VEGETATION

The surface area required is the additional surface area of flowing water that would be exposed due to the silvicultural activity. The total surface area of flowing water cannot be used because part of the stream (in the example, 54 ft²) is exposed under the existing pre-silvicultural activity vegetative conditions.

$$\begin{aligned} A_{\text{adjusted}} &= A_{\text{total}} \\ &\quad - A_{\text{exposed pre-silvicultural activity}} \qquad \text{(VII.7d)} \\ &= 795\ \text{ft}^2 - 54\ \text{ft}^2 \\ &= 741\ \text{ft}^2 \end{aligned}$$

Assuming that all vegetation is removed, the exposed surface area of flowing water would be 741 square feet in the example. If some of the current vegetative cover were to remain, the surface area shaded by the remaining vegetative cover would also be subtracted from A_{total}.

Determination of Maximum Potential Daily Temperature Increase, ΔT

Determine the maximum potential daily temperature increase in degrees Fahrenheit using H, Q, and A values as derived through the previous steps. Compute the maximum potential change in daily temperature assuming all riparian vegetation is removed using Brown's model:

$$\Delta T = \frac{AH}{Q}\, 0.000267 \qquad \text{(VII.3)}$$

where:

ΔT = maximum potential daily temperature increase in degrees Fahrenheit

A = adjusted surface area

Q = mean discharge that will occur within the exposed reach during critical period following silvicultural operation

H = adjusted heat load BTU/ft²-min

Equation VII.3 becomes:

$$\Delta T = \frac{A_{\text{adjusted}} H_{\text{adjusted}}}{Q} \quad 0.000267 \qquad \text{(VII.3a)}$$

(The use of subscripts indicates that the variables in Brown's original model, equation VII.3, have been refined in this handbook.)

In the example:

$$\begin{aligned} A_{\text{adjusted}} &= 741\ \text{ft}^2 \\ H_{\text{adjusted}} &= 3.94\ \text{BTU/ft}^2\text{-min} \\ Q &= 0.4\ \text{cfs} \end{aligned}$$

so that:

$$\Delta T = \frac{741\ \text{ft}^2 \times 3.94\ \text{BTU/ft}^2 - \text{min}}{0.4\ \text{cfs}}$$

$$0.000267 = 1.9°\ \text{F}$$

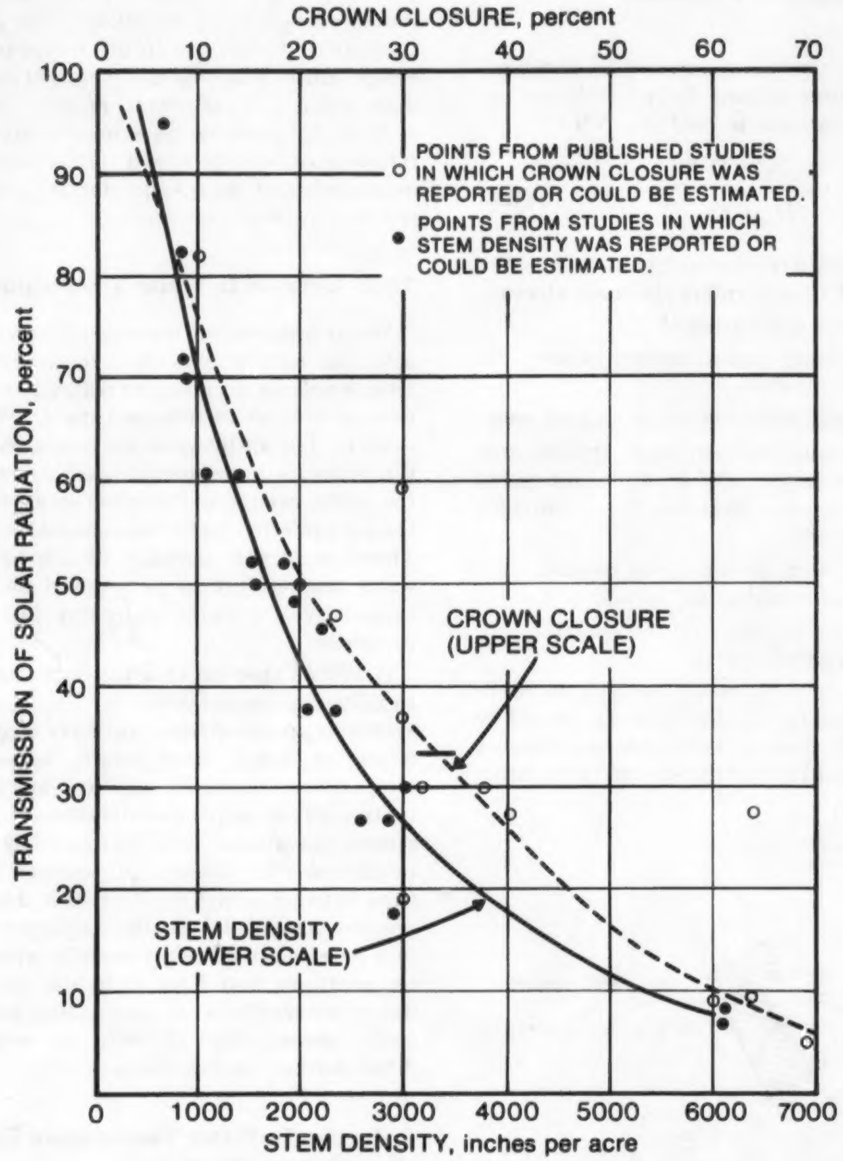

Figure VII.10.—Transmission of solar radiation as a function of stem density and crown closure (Reifsnyder and Lull 1965).

Evaluation Of Downstream Temperature Increases

To evaluate downstream impacts of increased water temperatures caused by silvicultural activity, a mixing formula is used (fig. VII.11):

$$T_D = \frac{D_M T_M + D_T T_T}{D_M + D_T} \qquad \text{(VII.8)}$$

where:

T_D = temperature downstream after the treated stream enters the main stream,

D_M = discharge main stream,

T_M = temperature main stream above the treated tributary,

D_T = discharge stream draining treated area,

T_T = temperature stream below treated area equals temperature above plus computed temperature increase (i.e., Brown's model) or $(T_A + \Delta T) = T_T$,

T_A = temperature stream above treated area (measured in field), and

ΔT = temperature increase computed using Brown's model.

The mixing ratio formula merely weights the resultant temperature (T_D) by discharge. (It should be noted that small streams with large temperature increases will be diluted if the stream flows into a larger water course.)

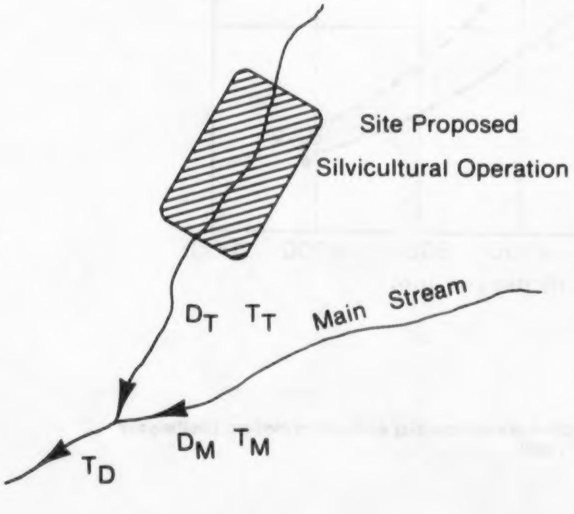

Figure VII.11.—Components of the mixing formula for evaluating the downstream impact of increased water temperature caused by silvicultural activities upstream.

Please note, there are two factors to consider when estimating the total downstream temperature increase due to upstream silvicultural activities. First, the total increase in water temperature caused by the operation itself must be determined (i.e., Brown's model). Second, the reduction of water temperature due to groundwater inflow must be determined. These factors must be estimated, and these estimates are generally subject to considerable error.

Total Increase In Water Temperature

Water temperature increases due to silvicultural activities have already been discussed. These increases will not normally be reduced by subsequent passage through undisturbed stands if the distance is short. The air temperature over a stream during the critical summer period is usually warmer than the water, even in undisturbed areas; furthermore, the net radiation input will continue to be positive. Therefore, it will generally be impossible for the water temperature to be reduced by convective, evaporative, or radiative energy loss to the atmosphere.

It follows that up to some limit, known as the equilibrium temperature, successive silvicultural activities on one stream will have a compounding effect on water temperature increases: water temperature increases due to downstream activities will be added onto increases caused by upstream operations. This compounding effect may be eliminated or minimized, however, if the travel time between activities is of such duration as to preclude arrival of water from an upstream activity to a lower activity before evening when cooler air temperatures and back radiation can lower the water temperatures, or when there are inflows of cooler groundwater of sufficient magnitude to dilute warmer surface water.

Reduction In Water Temperature Due To Groundwater Inflow

Groundwater is cooler than summer surface water, and it can reduce water temperature increases caused by silvicultural operations. Since groundwater temperature is fairly constant for wide areas, well and/or spring water temperatures can be used as a measure of groundwater temperature. A rough rule to be applied, if necessary, is that the groundwater temperature is approximately equal to the average annual air temperature.

Groundwater discharge can be measured in the field. Increasing discharge downstream can be assumed to be groundwater inflow only if there are no inflowing tributary streams and if there has been no recent precipitation event which might still be entering the stream as quick flow rather than base flow.

In trying to estimate groundwater discharges on small streams, the error of measurement is likely to be high and the potential for groundwater cooling the stream is quite large. This combination can lead to significant error in predicting temperature change below an exposed reach.

Once groundwater temperature and inflow have been measured, or estimated, the mixing ratio formula can be used to evaluate its impact on reducing temperature increases caused by silvicultural operations upstream. Groundwater that becomes surface flow is subject to radiation and convection heat influxes resulting in temperature increases.

The formula is the same mixing ratio as the one previously presented in equations V.2. and V.8.

$$T_D = \frac{D_G T_G + D_T T_T}{D_G + D_T} \qquad \text{(VII.9)}$$

These variables are represented on figure VII.12 where:

T_D = temperature downstream at some point of interest, degrees Fahrenheit,

D_G = discharge of the groundwater, cfs; it is equal to the discharge at the point of interest less the discharge immediately below the silvicultural operation,

T_G = temperature groundwater, degrees Fahrenheit,

D_T = discharge immediately below the silvicultural operation, cfs, and

T_T = stream temperature below the silvicultural operation which is equal to the temperature above plus computed temperature increase or $T_A + \Delta T = T_T$, and where:

T_A = temperature stream above the treated area (measured in field), and

ΔT = temperature increase computed using Brown's model.

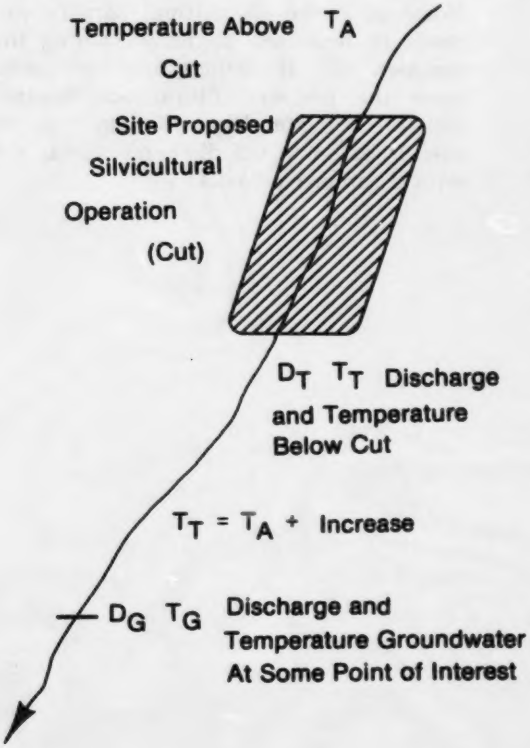
Temperature Above Cut T_A
Site Proposed Silvicultural Operation (Cut)
D_T T_T Discharge and Temperature Below Cut
$T_T = T_A +$ Increase
D_G T_G Discharge and Temperature Groundwater At Some Point of Interest

Figure VII.12.—Components of the mixing formula for evaluating the impact of ground water temperature and inflow on reducing temperature increases due to silvicultural activities upstream.

APPLICATIONS, LIMITATIONS, AND PRECAUTIONS

1. Application of the model should be limited to stream sections of less than 2,000 feet in length. Beyond this distance, evaporative and convective energy losses, assumed to be negligible in the simplified model, become important sources of dissipation.
2. Accurate measurement of data is critical.
    a. It is essential to measure the average width of flowing water when stream temperature is critical (i.e., during the summer months). Streambed or water surface width should not be used for computing average width of flowing water if any exposed rocks, gravel bars, or pools are present in the cross section; to do so would result in computed maximum temperatures in excess of actual values.

    b. Discharge should be measured whenever possible and should represent the mean discharge through the exposed reach of stream. If there will be no increase in discharge during the critical summer period following the silvicultural activity, the discharge measured before the activity may be used. However, if the silvicultural activity will result in increased discharges during the summer, all calculations must be based upon the post-silvicultural activity discharge. ("Chapter III: Hydrology" can be used to estimate the discharge during the critical summer period.)

    c. Shading, both vegetative and topographic, must be determined as accurately as possible. Angular canopy density measurements should be taken to estimate vegetative shading. All shading is important. Understory noncommercial trees, brush, and low shrubs may be more significant for shading purposes than commercial timber. Assuming the stream is completely shaded at all times is probably erroneous and will result in estimated temperature increases far above actual increases.

    d. The proportion of the exposed streambed composed of bedrock must be estimated in order to account accurately for the heat sink.
3. Small streams with braided flows require more accurate field measurements of stream width than larger, single channel streams.
4. The capacity of a stream for absorbing heat is limited. As stream temperature approaches air temperature, equilibrium will be reached.
5. The model does not consider inflowing cool ground water. Such a consideration could significantly reduce the maximum temperature increase predicted by the model. If inflowing ground water could alter the temperature increase, its impact can be evaluated by using a mixing formula (eq. VII.9).

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APPENDIX VII.A:

VALIDATION OF BROWN'S MODEL

Brown developed and verified his model in the West, and utilization by western forest hydrologists has had good results.

To determine its national applicability, a very limited validation of the model was conducted in the East using two treated, clear-cut watersheds (Watersheds 3 and 7) and a control (Watershed 4) on the Fernow Experimental Watershed, Parsons, West Virginia.

The field data collected from Watersheds 3 and 7 consisted of the length and width of the exposed stream reach following treatment, discharge, and percent bedrock in streambed. In addition, the actual water temperature was recorded so that the estimated water temperature increase, computed using Brown's model, could be compared with the actual increase. Water temperature of the control watershed was also measured and was used to approximate the water temperature of the treated watersheds before treatment.

Using Brown's model, initial estimations of the water temperature increases following treatment were +6° F to +10° F higher than the actual measured values. It was determined that the average stream width, not the average width of flowing water, was measured. When the average width of flowing water was measured Brown's model estimated within +1° F to +3° F of the actual water temperature increase, table VII.A.1. No data were available to estimate the amount of streamside vegetative shading and, therefore, the estimated values would tend to be high.

Table VII.A.1.—Summation of validation test using data (°F) from Fernow Experimental Watershed, Parsons, West Virginia

Watershed/ treatment	Estimated temperature using procedure presented	Measured temperature	Difference
	°F	*°F*	
3/clearcut	64	63	+1
7/clearcut	63	60	+3
4/control	---	58	---

This validation not only indicates that Brown's model is applicable for use in the East, but also reaffirms the importance of obtaining accurate field measurements. The model is only as accurate as the data that are used.

Actual computations for the two treated watersheds follow:

Watershed 3, Clearcut

L = 2,336 ft

W = 1.35 ft (average width flowing water)

[Initial width used was 3.30 ft but this was the average width of the stream.]

A = LW = 2,336 ft × 1.35 ft = 3,154 ft²

Latitude = 39°

Maximum water temperature occurs on August 28

Maximum Solar Angle = 60° on August 28

Bedrock = 20% Correction Factor = 0.95

H = 4 BTU/ft²–min

H_{adjusted} = H × Bedrock Correction Factor
= 4 BTU/ft² × 0.95
= 3.8 BTU/ft²–min

Q = 0.53 ft³/s

$$\Delta T = \frac{A\,H_{\text{adjusted}}}{Q}\,0.000267$$

$$= \frac{3{,}154\text{ft}^2\,(3.8\text{ BTU/ft}^2 - \text{min})}{0.53\text{ ft}^3/\text{s}}\,0.000267$$

$$= 6°\text{ F}$$

Water temperature = 58° F for Control Watershed 4 (not cut)

Control temperature + ΔT = Estimated water temperature of clearcut

58° F + 6° F = 64° F

Estimated temperature = 64° F[1]

Measured temperature = 63° F for Watershed 3

---

[1] *No information on shading brush; therefore estimated increase may be high.*

Watershed 7, Clearcut

L = 2,380 ft

W = 1.80 ft (average width flowing water)

[Initial width used was 2.60 ft, but this was the average width of the stream.]

A = LW = 2,380 ft = 2,380 ft (1.80 ft)
= 4,284 ft^2

Latitude = 39°

Maximum water temperature occurs on August 28.

Maximum Solar Angle = 60° on August 28

Bedrock = 25% Correction Factor = 0.95

H = 4 BTU/ft^2–min

$H_{adjusted}$ = H(Bedrock Correction Factor)
= 4 (0.95) = 3.8 BTU/ft^2–min

Q = 0.83 ft^3/s

$$\Delta T = \frac{A\,H_{adjusted}}{Q}\ 0.000267$$

$$= \frac{4{,}284\text{ft}^2\ (3.8\ \text{BTU/ft}^2 - \text{min})}{0.83\ \text{ft}^3/\text{s}}\ 0.000267$$

$$= 5^\circ\ \text{F}$$

Water temperature = 58° F for Control Watershed 4 (not cut)

Control temperature + ΔT = Estimated water temperature of clearcut

58° F + 5° F = 63° F

Estimated temperature = 63° F[2]

Measured temperature = 60° F for Watershed 7

---

[2] *No information of shading brush; therefore, estimated increase may be high.*

APPENDIX VII.B:

STREAMSIDE SHADING

Research conducted throughout the country has demonstrated that removal of commercial and noncommercial streamside vegetation will result in increased water temperatures due to increased exposure of the water surface to direct radiation. Using Brown's model, the magnitude of the temperature increase varies with the proportion of stream exposed.

Maximum increases are associated with clearcutting in the streamside area. The increases reported range from a few degrees to 28° F, depending upon the area and discharge of the streams affected (Eschner and Larmoyeux 1963, Meehan and others 1969, Brown and Krygier 1970, Brown 1971, and Swift and Messer 1971). Water temperature can be maintained, however, if there is adequate shading of the water surface during periods of maximum solar radiation. Shading may be topographic, vegetative, or a combination of both.

TOPOGRAPHIC SHADING

Shading by topographic features includes not only the major land forms, but also the minor changes in relief associated with streambanks. The potential for topographic shading is determined partly by orientation of the stream with the sun, and partly by latitudinal location.

Orientation of topographic features in relation to stream and sun is crucial. Streams oriented east-west may be shaded in the morning by topographic features to the south. North-south oriented streams may be shaded in the morning by topographic features situated to the east, and to the west in the afternoon.

Latitudinal position of the stream influences the extent to which topography or surrounding vegetation may be effective because latitude determines solar angle. The path of the sun varies during the year from 23-½° N latitude (June 21) to 23-½° S latitude (December 22). When the solar angle is vertical, directly overhead, there is no possibility for topographic shading; as the angle decreases from the vertical, the probability and effectiveness of topographic shading are increased.

VEGETATIVE SHADING

Vegetative shading normally will be the dominant onsite factor controlling the amount of solar radiation directly striking the water surface. Shading is not limited to dominant and codominant tree species, but encompasses all vegetation to include brush, shrubs, and other low-growing species.

1. The effectiveness of the shade created will vary with vegetation type. The effect of type includes not only species differences but also age class. The proportion of tree bole in a live crown influences the extent of shade provided. Mature coniferous stands, with much of the lower bole free of limbs, may offer only partial shade; whereas younger stands, with most of the bole in live crown, will provide adequate shade for small headwater streams.
2. The density or spacing of vegetation also determines the amount of radiation the water receives. In poorly stocked stands with low density and crown closure, the trees may be so widely spaced as to preclude effective shading of the water course.
3. For a stream of a given width, the height of vegetation necessary to effectively shade a water course will vary with the distance from the stream and the solar angle and orientation. There is a direct relationship between distance from the stream and height of vegetation necessary to provide adequate shade (fig. VII.B.1).
4. For a stream of a given width, there is also a relationship between solar angle and height of vegetation needed to provide stream shading. When the solar angle is perpendicular to the stream surface (i.e., directly overhead), the only shading is that from vegetation overhanging the water; the height of riparian vegetation becomes irrelevant (fig. VII.B.2).
5. Orientation of the sun with respect to the stream determines the "effective" width of the stream versus the actual stream width. Effective width is the length of shadow required to reach completely across the stream. The actual width would equal the effective width only when the sun was oriented at right angles to the stream

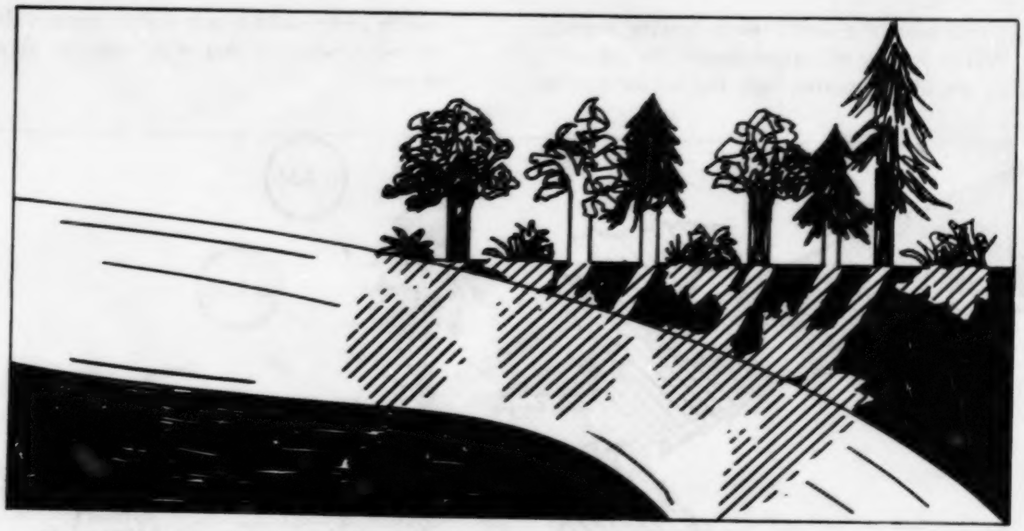

Figure VII.B.1.—Low growing shrubs and brush adjacent to a water course may provide adequate shade, while taller vegetation is necessary further from the stream.

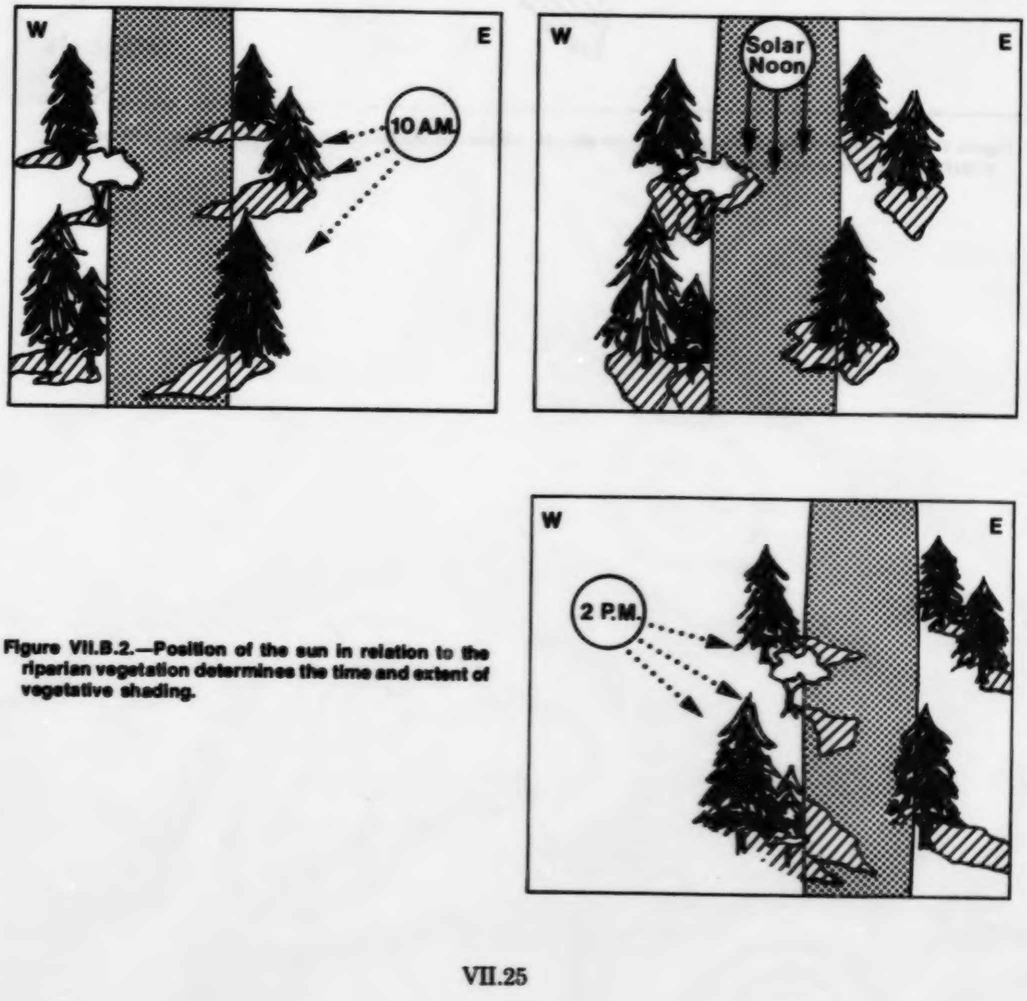

Figure VII.B.2.—Position of the sun in relation to the riparian vegetation determines the time and extent of vegetative shading.

(e.g., due east of a north-south flowing stream, fig. VII.B.3). At all other times the effective width would be greater than the actual stream width and would reach a maximum value (infinity) when the sun was directly above the stream.

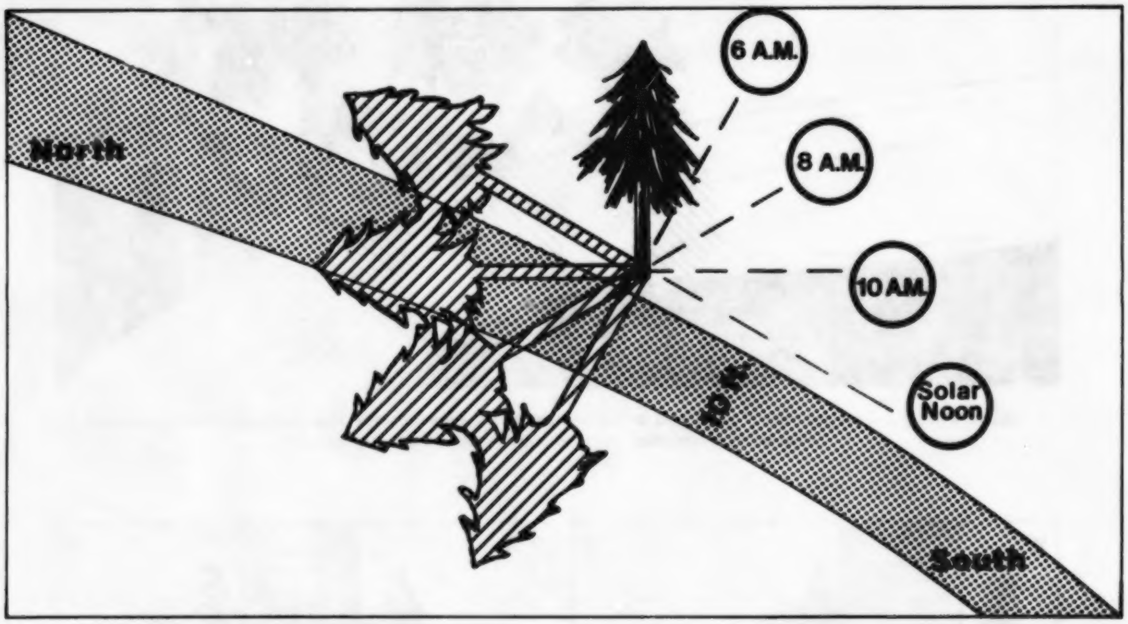

Figure VII.B.3.—Orientation of the sun with the stream determines the length of shadows necessary to completely shade the water surface.

APPENDIX VII.C:

WATERSIDE AREAS

Designation of waterside areas by land managers can be used to prevent or minimize water temperature increases. It is not feasible to establish general standards for waterside areas; however, Brazier and Brown (1973) have evaluated some of the factors that determine the effectiveness of such areas.

COMMERCIAL TIMBER VOLUME

Commercial timber volume is not a significant parameter for determining shading of the stream by the vegetation in the waterside area. Due to the relatively narrow width of the headwater (1st, 2nd, and 3rd order) streams, the effectiveness of the shade produced by noncommercial tree species, shrubs and low growing vegetation can be as great as that produced by commercial species. In addition, there is a great variability between volume (board feet) and crown closure (density) which is manifested in the spacing and number of trees per unit of area. A few large trees with a large commercial volume may have little protective capability because of wide spacing, or because crowns may be too high or sparse to shade the streams. Many pole-sized trees with a smaller commercial volume may effectively shade the stream due to their close spacing and dense canopy.

STRIP WIDTH

In the past, land managers have arbitrarily designated waterside areas according to such factors as width (which has ranged from less than 50 feet to several hundred feet), topography, or percent slope. Strip width alone is not an important factor in determining effectiveness of the vegetation in shading the stream. Strip width is critical for stream protection only as it is related to canopy density, canopy height and stream width (fig. VII.C.1).

Canopy densities of less than about 15 percent angular canopy density (ACD) do not provide sufficient shade for a measurable reduction in heat load. Above this value, however, there should be a

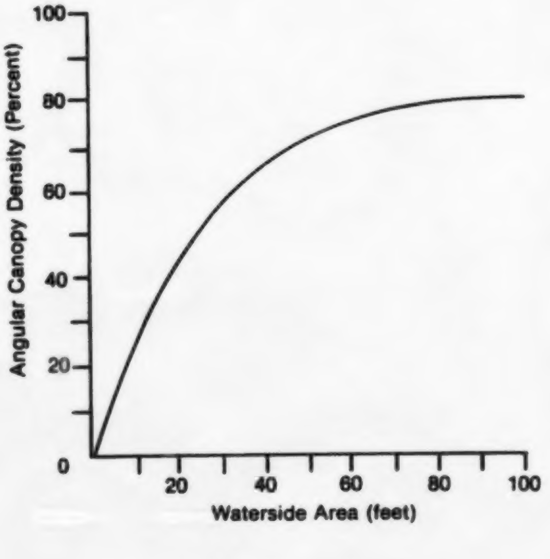

Figure VII.C.1.—The relation between waterside area width and angular canopy density (Brazier and Brown 1973)

direct relationship between heat reduction and angular canopy density until the canopy approaches 100 percent ACD. As the density approaches 100 percent, additional increments in density should block less radiation than the previous increment. Therefore, with greater canopy density, the relationship between the amount of heat blocked and the angular canopy density should approach some maximum value at a level less than complete blockage of all incidental radiation (fig. VII.C.2).

When the angular canopy density is not known or cannot be measured, stream shading may be estimated using a clinometer or abney level to identify those crowns which contribute shade to the stream. Vertical crown closure values can be used to obtain a rough estimate of stream shading, but it should be noted that angular canopy density and vertical crown closure are normally significantly different. The importance of obtaining accurate measurements of stream shading cannot be overemphasized; it is the basis for establishing effective waterside area widths to protect the stream from excessive temperature increases.

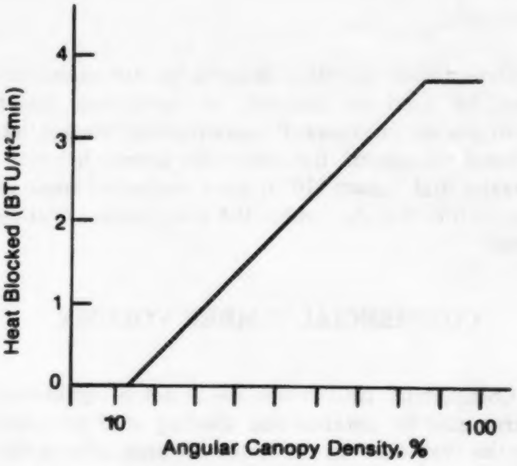

Figure VII.C.2.—The relation between angular canopy density (ACD) and heat blocked (ΔH) (Brazier and Brown 1973).

APPENDIX VII.D:

GENERAL RELATIONSHIPS BETWEEN LIGHT INTENSITY OR TRANSMISSION OF SOLAR RADIATION AND VEGETATIVE COVER

Table VII.D.1.—Effects of stand density removal on light intensity (%) (USDA For. Serv.)

Quantity removed	Percent Fully stocked stand removed	Light intensity
Stem density	0	8
	25	14
	50	26
	[1]75	[1]55
Canopy closure	0	4
	25	6
	50	16
	75	43
Basal area	0	10
	25	15
	50	27
	75	52

[1] Example: Removing 75 percent of the stems would increase the light intensity from 8 percent to 55 percent.

Table VII.D.2.—Effects of tree spacing (ft) on light intensities (%) (USDA, For. Serv.)

Spacing (ft)	Trees (number/ac)	Light intensity
4 × 4	2,721	15
6 × 6	[1]1,210	[1]16
7 × 7	889	36
9 × 9	538	60

[1] Example: By removing slightly less than half the trees (538) from a 6 × 6 foot spacing (1,210) increases the light intensity from 16 percent to 60 percent.

Table VII.D.3.—Percent light intensity through small-[1] and large-[2] crown trees (Reifsnyder and Lull 1965)

Stem density (in/ac)	Basal area (ft/ac)	Percent of small-crowned trees 0-33	34-67	68-100
		Percent light intensity		
200	20	87	90	94
700	60	57	70	78
1,200	100	34	50	63
1,900	180	13	30	43
3,700	400	7	10	12

[1] Small—western white pine, western larch, and Douglas-fir.

[2] Large—grand fir, western hemlock, and western red cedar.

Table VII.D.4.—Percent light intensity through eastern conifers (Reifsnyder and Lull1965)

Species	Basal area (ft^2/ac)	Light intensity
White pine, balsam fir	209	7
White pine, white spruce, balsam fir	171	9
White pine, red pine	103	27
White, red, jack pine, white spruce, balsam fir	103	25

Table VII.D.5.—Percent light intensity through conifer plantations (Reifsnyder and Lull 1965)

Spacing (ft)	Light in open
2 × 2	15.9
4 × 4	36.0
6 × 6	46.6
8 × 8	55.4

Table VII.D.6.—Stand basal area (ft^2/a) and equivalent solar loading (BTU/ft^2-min) beneath the canopy (Hughes 1976, personal communication)

Solar loading % of open	Total stand basal area Dense crown[1]	Moderate crown[2]
10	255	400
15	200	305
20	160	245
25	135	210
30	120	180
35	105	160
40	90	140
45	80	120
50	70	105
55	60	90
60	55	80
65	45	70
70	35	55
75	30	45
80	25	35
85	20	30
90	10	20
95	5	10
100	0	0

[1] Dense crown includes normally stocked stands of western hemlock, western redcedar, Sitka spruce, Pacific silver fir, and uneven aged mixed stands. Also overstocked hardwood stands.

[2] Moderate crown includes even aged Douglas-fir stands, and normally stocked red alder or black cottonwood.

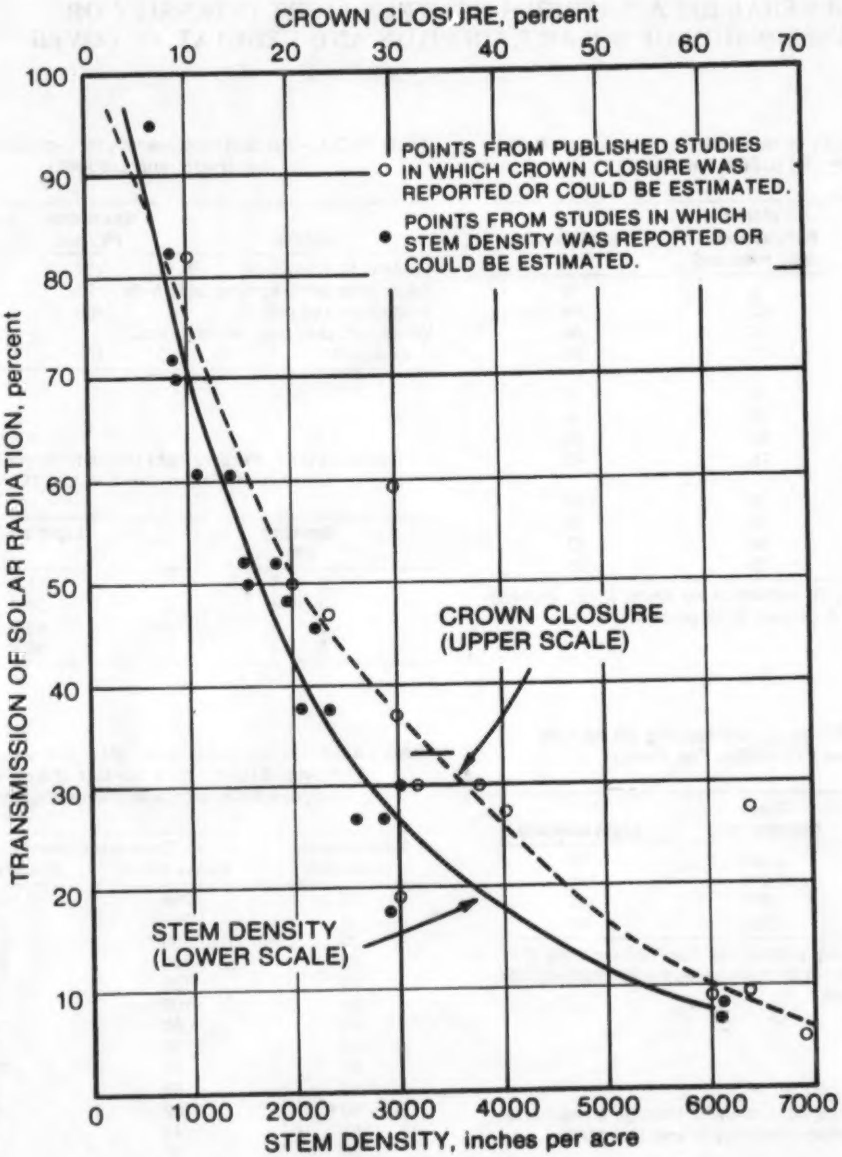

Figure VII.D.1. Transmission of solar radiation as a function of stem density and crown closure (Reifsnyder and Lull 1965).

Chapter VIII

PROCEDURAL EXAMPLES

this chapter has been prepared by the coordinators for chapters III-VII

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INTRODUCTION

This chapter provides examples of silvicultural activities on two hypothetical watersheds—one in a rain dominated hydrologic region (Grits Creek) and one in a snow dominated region (Horse Creek). It demonstrates the procedural analyses that would be conducted to evaluate the potential non-point source pollution associated with each example. Where such potential non-point source pollution would exceed established water quality objectives, the procedure for considering control opportunities, thereby revising the original silvicultural plan, is explained.

All figures, tables, and worksheets mentioned within this chapter are referenced according to their original chapter number. Only figures unique to chapter VIII have been given "VIII" numbers.

PROCEDURAL EXAMPLE FOR GRITS CREEK—A RAIN DOMINATED HYDROLOGIC REGION

DESCRIPTION OF AREA AND PROPOSED SILVICULTURAL ACTIVITY

Foresters from the Appalachian Hardwood Products Company[1] inventoried a 356-acre tract of hardwoods (fig. VIII.1) owned by the company in the southern Appalachians. The watershed is at a latitude of 35°N. The baseline leaf area index (LAI) is 6. Dominant aspect is southwest, and the average rooting depth for the watershed is 4 feet. The tract was divided into timber compartments A, B, and C (fig. VIII.1) based upon stand composition; management prescriptions were proposed for each. A description of each timber compartment and the prescribed management options follows.

Compartment A is an 84-acre stand along the ridgetop of the watershed. It is composed of low quality northern red oak and a dense laurel-rhododendron understory. Trees are short and branchy because of repeated ice damage, and the growth potential is low in these steep, rocky, shallow soils. Because of high recreation use and the poor site condition for timber production, the company forester recommended that no silvicultural activity be conducted.

Poor oak-hickory stands are present on the lower slopes in compartment B, producing little timber; but soils are deep, well watered, and capable of timber production. The proposed residual leaf area index is estimated to be 2. The forester recommended that the 180-acre timber stand be regenerated by clearcutting all woody vegetation after harvesting mechantable timber.

Compartment C, 92 acres, contains a 40-year-old stand of excellent yellow poplar mixed with overmature remnants of other cove hardwoods. It was originally estimated that the yellow poplar would be from 85 to 120 feet high at age 50, but the growth rate of the overcrowded stand has slowed during the last 7 years. A thinning has been recommended by the company forester to increase growing space for crop trees. Additional cuts will be required at 20-year intervals. The proposed residual leaf area index is estimated to be 3. Compartment C would be reevaluated for a possible clearcut in 40 years, in accordance with the company's policy of even-aged management. Then the site would be regenerated to yellow poplar or other desirable species.

Based upon these management prescriptions, engineering and harvesting system analyses were made. Two alternatives were developed for analysis using the basic steps outlined in "Chapter II: Control Opportunities," Appendix II.A, example two. The significant resource impacts were "bare soil" and "compaction." Based on a knowledge of the site and professional judgment, the following control opportunities were selected.

1. Prescribe yarding and skidding layout.
2. Revegetate treated areas promptly, as local conditions dictate.

The two engineering and harvesting alternatives were based on different yarding systems, road locations, and revegetation prescription. Alternative A was based on tractor yarding with road locations shown in figure VIII.2. Alternative B was based on cable yarding systems and required an additional road (fig. VIII.2) to achieve reasonable yarding distances. Revegetation of all roads, including running surfaces, was planned in Alternative B. Both alternatives were analyzed and the results compared to water quality objectives.

Water Quality Objectives

Water quality objectives were established for the Grits Creek area by the Regional Planning Commission in conjunction with State 208 planners. The established objectives required that channel stability be maintained, that total potential sediment discharge be limited to 25.5 tons/yr and that water temperature increases be no greater than 3° F.

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[1] *This is intended to be a fictitious company name; any similarity to an actual company is entirely coincidental.*

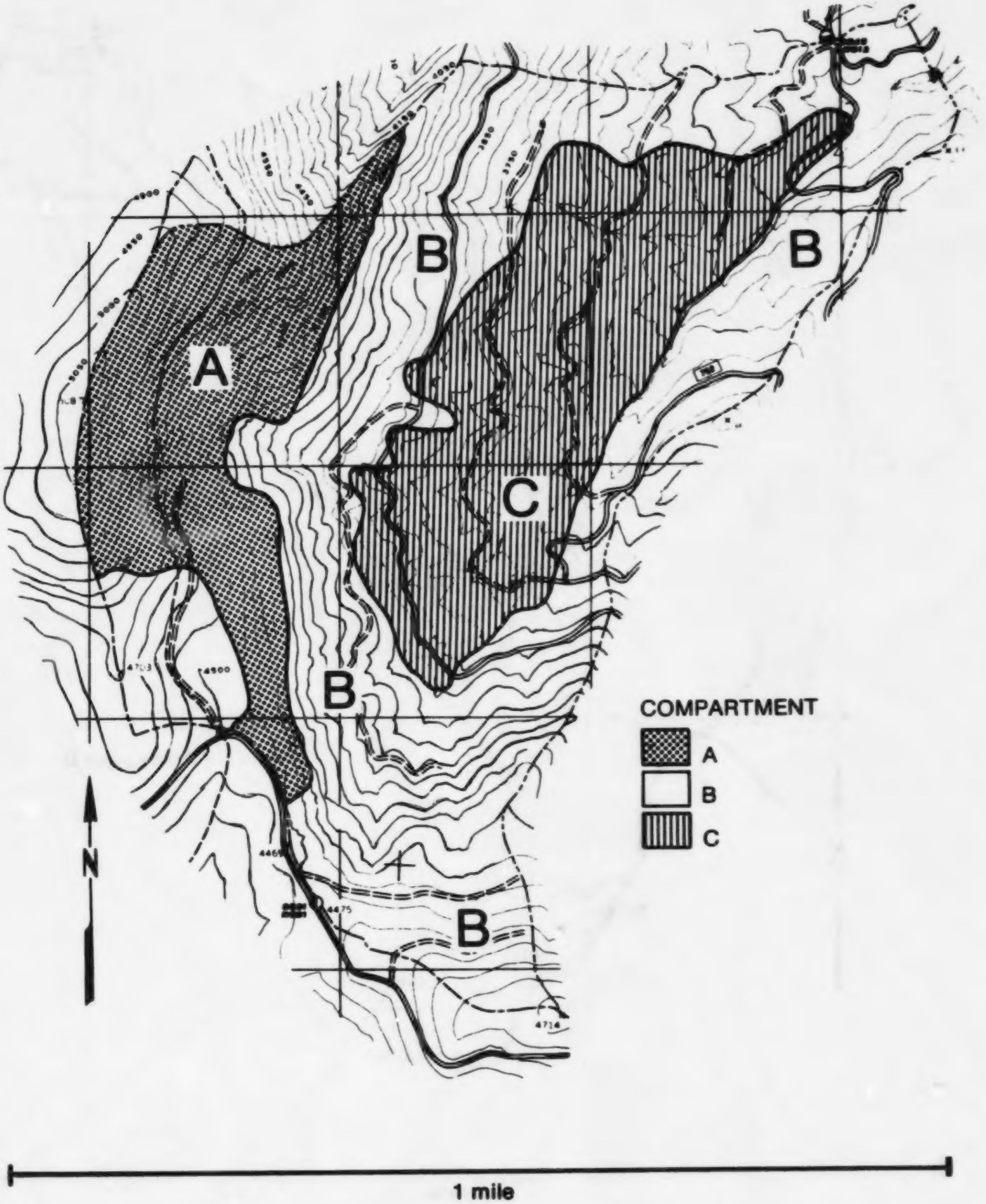

Figure VIII.1.—Timber compartments for Grits Creek watershed.

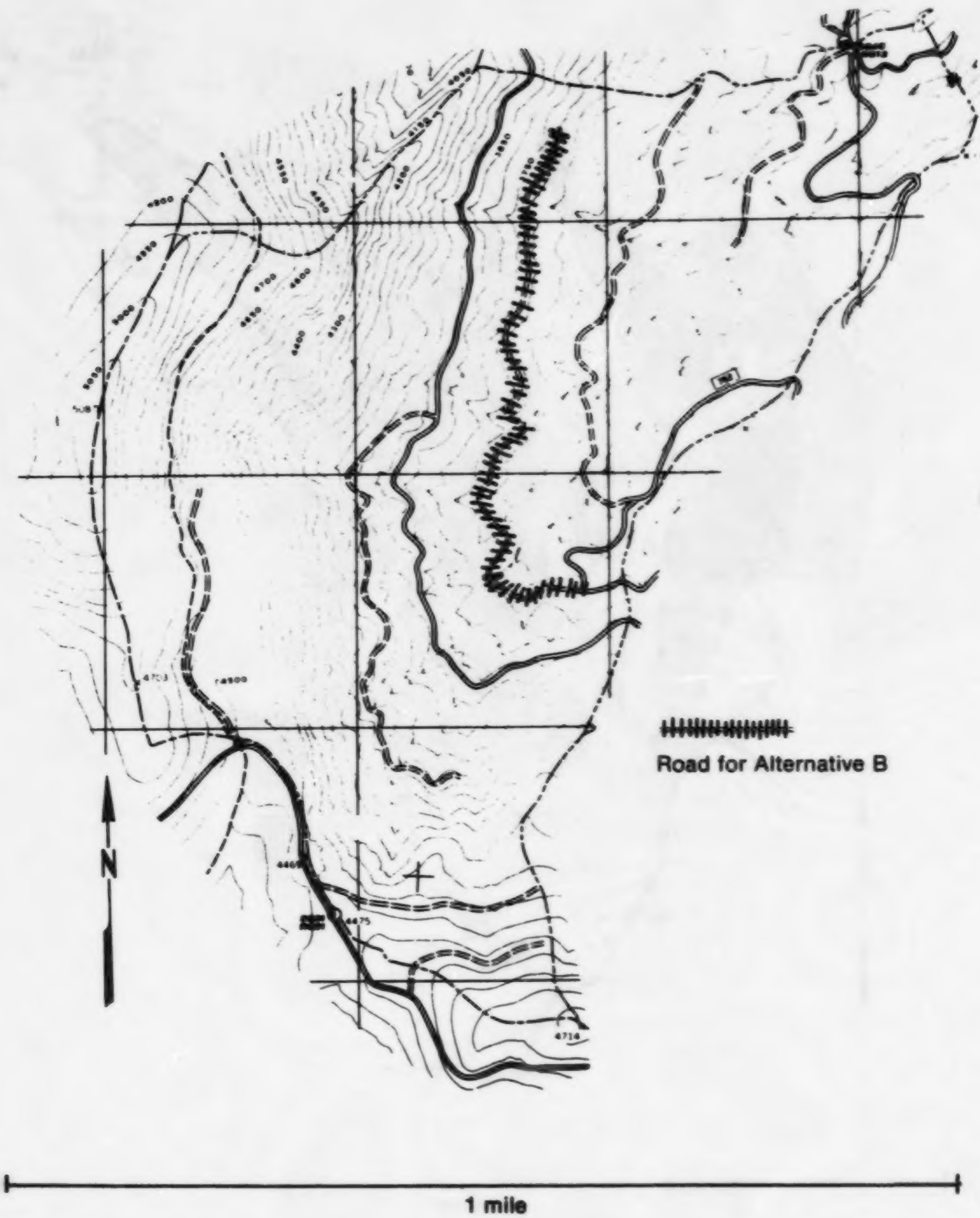

Figure VIII.2.—Road constructed for Alternative B, Grits Creek watershed.

DATA BASE

The collected data are presented in table VIII.1 and worksheets IV.1, IV.2, V.1, and VII.2. (Proposed and revised worksheets are located at the end of section "Procedural Example for Grits Creek—. . .") Soils were mapped by the Soil Conservation Service. All data presented are required, unless otherwise specified, for a complete water resource evaluation of Grits Creek, the major drainage in the tract. The complete evaluation requires analyses within the following categories (numbers for the corresponding chapters in this handbook appear in parentheses):

Hydrology (III)
Surface Erosion (IV)
Total Potential Sediment (VI)
Temperature (VII)

HYDROLOGY ANALYSIS

The hydrology analysis serves as a guide to estimate change in potential streamflow associated with silvicultural activities in rainfall dominated regions. The methodology and procedures presented in this document are only guidelines to complement professional judgment for a particular situation.

Water Available For Streamflow—Existing Conditions

Step 1. — The first step in the hydrologic evaluation of Grits Creek is to estimate the water available for streamflow under existing conditions using worksheet III.1. The necessary procedures are outlined below. (Numbers in parentheses refer to items or columns on the worksheet.)

(1) Watershed name. — Grits Creek may be treated as a single watershed unit for hydrologic evaluation (see "Chapter III: Hydrology").

(2) Hydrologic region. — Grits Creek is located in hydrologic region 2, Appalachian Mountains and Highlands. The region is also described in chapter III.

(3) Total watershed area. — Drainage size is 356 acres.

(4) Latitude. — The latitude of Grits Creek is 35°N. This is necessary input since evapotranspiration was found to be a partial function of latitude in region 2.

(5) Season. — The seasons for rainfall dominated regions are: fall (September, October, November); winter (December, January, February); spring (March, April, May); and summer (June, July, August).

(6) Compartment. — The entire watershed is considered to be unimpacted under existing conditions (i.e., no areas affected by previous silvicultural activities).

(7) Silvicultural state. — Watershed areas are grouped into zones of similar hydrologic response as identified by silvicultural or vegetational state. For Grits Creek, the only silvicultural state is "forested." There is a single silvicultural prescription for the existing condition consisting of a single silvicultural state — forested.

(8) Area, acres. — The silvicultural zone is "forested," and this forested area is 356 acres.

(9) Area, %. — This refers to the percentage of the prescription area in each silvicultural state. In this case, the forested area is 100 percent (1.00 as a decimal percent) of the prescription area.

(10) Precipitation. — Enter estimates of seasonal precipitation to the nearest 0.1 cm. For Grits Creek, precipitation averaged 23.3, 75.2, 60.5, and 27.0 cm for fall, winter, spring, and summer, respectively. Analysis requires precipitation and evapotranspiration to be entered in centimeters.

(11) Baseline ET. — Baseline evapotranspiration (ET) for a latitude of 35°N is taken from figure III.11. Respective values for fall, winter, spring, and summer are 20.1, 8.9, 13.0, and 39.1 cm.

(12) Basal area. — Since the leaf area index is known, basal area is not needed.

(13) Leaf area index. — The leaf area index has been estimated as 6 for Grits Creek. Leaf area index does not change with seasons since leaf fall is taken into account when ET estimates are determined.

(14) ET modifier coefficient. — Evapotranspiration modifier coefficients, as functions of leaf area index and season, are obtained from figure III.16. For undisturbed forested areas, the ET modifier coefficent is 1.0 for all seasons.

(15) Rooting depth modifier coefficient. — Rooting depth modifier coefficients are taken from figure III.19 for an average soil depth. In this example, all rooting depth modifier coefficients are equal to 1.0.

Table VIII.1.--A summary of information required for the analysis procedures, Grits Creek watershed

Description of the information required	Information requirements by chapter[1]					Information for watershed
	III	IV	V	VI	VII	
Information on hydrology						
Flow--hydrograph or flow duration curve	O					
Bankful				X,P		N/A
Baseflow					X,P	Lower reach: 0.5cfs; middle reach: 0.3cfs; Upper reach: 0.2 cfs
Representative flows to be used to establish suspended and bedload rating curves				X		Figure VIII.10
Width stream						
Bankful				X		N/A
Baseflow (average width flowing water)					X	Lower reach: 5.0 ft; middle reach: 3.5 ft; upper reach: 2.0 ft
Depth stream (bankful)				X		N/A
Water surface slope				X		N/A
Suspended sediment for representative flows				X		Figure VIII.10
Bedload sediment for representative flows				X		N/A
Channel stability rating				X		Fair
Orientation stream--azimuth					X	35°
Low flow period (date)					X	Last week of August
Percent streambed in bedrock					X	75%
Bedrock adjustment factor					P	Figure VII.9; 0.15
Length reach exposed					X	Lower reach: 2,000 ft; middle reach: 1,900 ft; upper reach: 1,000 ft
Travel time through reach					X	Lower reach: 65 min; middle reach: 50 min; upper reach: 28 min

[1] P - Data provided in this handbook
O - Optional data, not required for analysis
X - User-provided data

Table VIII.1.--continued

Description of the information required	Information requirements by chapter					Information for watershed
	III	IV	V	VI	VII	
Information on hydrology--continued						
Normalized hydrographs of potential excess water	P					N/A
Normalized flow duration curves	P					Figure III.22
Date of peak snowmelt discharge	O					N/A
Map of drainage net	X	X	X	X	X	Figure VIII.4
Presence of springs or seeps			X			N/A
Change stream geometry						
Water surface slope				X		N/A
Bankful width				X		N/A
Bankful depth				X		N/A
Information on climate						
Precipitation						
Form	X	O	X			Rain
Annual average	X					186.0 cm
Seasonal distribution	X	O				9/1 to 11/30 : 23.3cm ; 12/1 to 2/28 : 75.20m ; 3/1 to 5/31 : 60.5cm ; 6/1 to 8/31 : 27.0cm
Storm intensity and frequency		O	X			N/A
Extreme event						
1 yr, 15-minute storm intensity		X				2.5 in/hr
Drop size		O				N/A
Precipitation--ET relationship	P					N/A
Wind direction	X					N/A

Table VIII.1.--continued

Description of the information required	Information requirements by chapter III	IV	V	VI	VII	Information for watershed
Information on climate--continued						
Snow retention coefficient	X,P					N/A
Date snowmelt begins	O					N/A
Maximum snowmelt rate	O					N/A
Radiation						
Solar ephemeris					P	Figure VII.2
Heat influx					P	Figure VII.7
Iso-erodent [illegible] for "R" factor		P				Figure IV.1; 300
Information on vegetation						
Species	X				X	Southern and cove hardwood
Height						
Overstory	X	X			X	80 ft
Understory		X			X	10 ft to 60 ft
Riparian vegetation					X	2 ft to 12 ft
Presence phreatophytes			X			N/A
Crown closure (%)					X	Lower reach: 90% overstory, 60% understory; middle reach: 90% overstory, 55% understory; upper reach: 80% overstory, 50% understory
Cover density	P	X				N/A
Leaf area index (pre)	X					6
Basal area	O					N/A
Basal area--C_{dmx} relationship	P					N/A
Ground cover		X				Worksheet III.2

Table VIII.1.--continued

Description of the information required	Information requirements by chapter					Information for watershed
	III	IV	V	VI	VII	
Information on vegetation--continued						
Percent transmission solar radiation through canopy					X,P	Tables VII.0.1 to III.0.6, figure VII.0.1; lower reach: 5% pre, 15% post; middle reach: 5% pre, 10% post; upper reach: 5% pre, 10% post
Percent stream shaded by brush					X	Lower reach: 25%; middle reach: 40%; upper reach 65%
Baseline ET	X,P					Figure III.11
ET modifier coefficient	P					Figure III.16
Rooting depth	X					Average
Rooting depth modifier coefficient	P					Figure III.19
Information on soils and geology						
Depth soil	X		X			Worksheet IV.2
Percent sand (0.1-2.0 mm)		X				Worksheet IV.1
Percent silt and very fine sand		X				Worksheet IV.1
Percent clay		X	X			Worksheet IV.1
Percent organic matter		X				Worksheet IV.1
Soil texture		X				Worksheet IV.1
Soil structure		X				Worksheet IV.1
Permeability/infiltration		X	X			Worksheet IV.1 and worksheet III.7
Presence of hardpan		X	X			No
Nomograph for "K" factor		P				Figure IV.3
Baseline soil-water relationships	X,P					N/A
Soil-water modifier coefficients	P					N/A
Jointing and bedding planes			X			N/A

Table VIII.1.--continued

Description of the information required	Information requirements by chapter					Information for watershed
	III	IV	V	VI	VII	
Information on soils and geology--continued						
Soils map	O	X	X			Figure VIII.6
Previous mass movements			X			N/A
Number			X			N/A
Location			X			N/A
Unit weight dry soil			X			N/A
Delivery potential			P			N/A
Percent silt and clay delivered			X			N/A
Median size coarse material			X			N/A
Information on topography						
Map (hydrologic region)	X	X	X	X	X	USGS map, figure VIII.4; hydrologic region 2
Latitude	X				X	35°
Size watershed	X					356 acres
Elevation	X					Ranges from 2750 to 4720 ft
Aspect	X					Southwest
Slope						East 53%; west 50%
Length		X				Worksheet IV.2
Gradient		X	X		X	Figure VIII.1 and worksheet IV.2
Dissection			X			N/A
Shape/Irregularity		X	X			Concave and straight
Nomograph for "LS" factor		P				Figure IV.3

Table VIII.1.--continued

Description of the information required	Information requirements by chapter III	IV	V	VI	VII	Information for watershed
Information on topography--continued						
Surface roughness		x				Moderately rough to smooth
Information on the silvicultural activity						
Past history						
Harvesting	x	0				Some cutting early 1900's
Fires	x	0				N/A
Other disturbances	x	0				N/A
Proposed harvest						
Location units	x	x				Figure VIII.7 and worksheet IV.2
Size cuts	x	x				Figure VIII.7 ; 180 acres clearcut, 92 acres thinned
Leaf area index removed	x					Clearcut 4 ; thinned 3
Cover density removed	x					N/A
Basal area removed	x					N/A
Cover density overstory remaining		x				Worksheet IV.2
Cover density understory remaining		x				Worksheet IV.2
Average minimum canopy height		x				N/A
Slash and duff--litter		0				
Cover percent		x				Worksheet IV.2
Height	x					N/A
Percent bare soil		x				Worksheet IV.2

Table VIII.1.--continued

Description of the information required	Information requirements by chapter					Information for watershed
	III	IV	V	VI	VII	
Information on silvicultural activity--continued						
Transportation system						
Area disturbed	x	x				Figure VIII.2 and worksheet IV.2
Location	x	x				Figure VIII.2 and worksheet IV.2
Cut slopes (location and slope)		x				Worksheet IV.2; length: 3.5 ft-8.0 ft; slope: 170% - 180%; Figure VIII.2
Fill slopes (location and slope)		x				Worksheet IV.2; length: 2.0 ft-10.0 ft; slope: 100%; Figure VIII.2
Cut and fill vs. full bench		x	x			Cut/fill
Inslope vs. outslope		x				Outslope
Surface						
Width		x				12 ft to 13 ft
Gradient		x				0% to 1%
Surfacing (amount and kind)		x				Bare earth
Road density			x			N/A
Harvesting system		x	x			Tractor yarding
Landings						
Location	x	x				Figure VIII.2 and worksheet IV.2; along roads
Size	x	x				Worksheet IV.2; variable
Gradient		x				Worksheet IV.2; variable
Ground cover		x				Worksheet IV.2
Time for vegetative recovery of disturbed surfaces		x				N/A

(16) Weighted adjusted ET. — The weighted adjusted ET is calculated by multiplying baseline ET [col. (11)], ET modifier coefficient [col. (14)], rooting depth modifer coefficient [col. (15)], and area as a decimal percent [col. (9)]. Weighted adjusted ET values for fall, winter, spring, and summer are calculated as 20.1, 8.9, 13.0, and 39.1 cm, respectively.

(17) Weighted adjusted seasonal ET. — The sum of weighted adjusted ET values [col. (16)] for a season equals the weighted adjusted evapotranspiration for that season. Values are in centimeters rounded off to one decimal place.

Season	Weighted adjusted seasonal ET
Fall	20.1 cm
Winter	8.9 cm
Spring	13.0 cm
Summer	39.1 cm

(18) Water available for seasonal streamflow. — The difference between weighted adjusted seasonal ET [col. (17)] and seasonal precipitation [col. (10)] is the water potentially available for seasonal streamflow. For Grits Creek, fall, winter, summer, and spring potential streamflows were 3.2, 66.3, 47.5, and −12.1 cm, respectively.

(19) Annual ET. — The sum of adjusted seasonal ET values [col. (17)] is annual ET. This is 81.1 cm for Grits Creek.

(20) Water available for annual streamflow. — The sum of water available for seasonal streamflow values [col. (18)] is the water available for annual streamflow. This is 104.9 cm for Grits Creek.

Water Available For Streamflow—After Proposed Silvicultural Activity

Step 2. — The second step in the hydrologic evaluation of Grits Creek is to estimate the water available for streamflow if the proposed silvicultural activity is implemented. The necessary steps in worksheet III.2 are detailed below. (Numbers in parentheses refer to items or columns in the worksheet.) Since the acreage cut does not change for the two management alternatives, the analysis is the same.

(1)-(5). — Same as worksheet III.1.

(6) Compartment. — For the proposed condition of Grits Creek, there are two compartments: impacted and unimpacted. The impacted compartment includes those areas affected directly or indirectly by the proposed silvicultural activities, while the unimpacted compartment includes areas unaffected by the proposed silvicultural activities.

(7) Silvicultural state. — Watershed areas are grouped into zones of similar hydrologic responses as identified by silvicultural or vegetational state. For the proposed condition of Grits Creek, the unimpacted compartment has one silvicultural state—forested. For the impacted zone, there are two—clearcut and thinned. As with the existing condition, there is one silvicultural prescription. However, this prescription consists of three silvicultural states — forested, clearcut, and thinned.

(8) Area, acres. — For the proposed condition, the silvicultural states are forested, clearcut, and thinned with respective areas of 84, 180, and 92 acres.

(9) Area, %. — The area of each silvicultural state in column (8) is divided by item (3), total watershed area, and rounded off to the third decimal place. In this example, decimal percentage for forested, clearcut, and thinned zones and are 0.236, 0.506, and 0.258, respectively.

(10) Precipitation. — Seasonal precipitation to the nearest 0.1 cm is entered by the user. For Grits Creek, mean seasonal precipitation was 23.3, 75.2, 60.5, and 27.0 cm for fall, winter, spring, and summer, respectively.

(11) Baseline ET. — Baseline ET is the same for each silvicultural state within a season. The values taken from figure III.11 for a latitude of 35°N are 20.1, 8.9, 13.0, and 39.1 cm for fall, winter, spring, and summer seasons, respectively.

(12) Basal area. — Since the leaf area index (LAI) has been estimated, basal area data are unnecessary.

(13) Leaf area index. — Leaf area index (LAI) values have been estimated by a professional forester as 2 and 3 for clearcut and thinned areas, respectively.

(14) ET modifier coefficient. — Evapotranspiration modifier coefficients, as functions of leaf area index and season, are obtained from figure III.16. In this example, the modifier coefficients are:

Season	Forested	Clearcut	Thinned
Fall	1.00	0.81	0.90
Winter	1.00	0.65	0.76
Spring	1.00	0.60	0.72
Summer	1.00	0.69	0.84

(15) Rooting depth modifier coefficient. — Rooting depth modifier coefficients are taken from figure III.19 for an average soil depth. Here, all rooting depth modifier coefficients are equal to 1.0.

(16) Weighted adjusted ET. — Multiplication of baseline ET, ET modifier coefficient, rooting depth modifier coefficient, and area as a decimal percent yields adjusted ET values as follows:

Season	Forested	Clearcut	Thinned
Fall	4.74 cm	8.23 cm	4.67 cm
Winter	2.10 cm	2.93 cm	1.75 cm
Spring	3.07 cm	3.95 cm	2.41 cm
Summer	9.23 cm	13.65 cm	8.47 cm

(17) Weighted adjusted seasonal ET. — Summation of adjusted ET values by activity yields weighted adjusted seasonal ET for the watershed. Fall, winter, spring, and summer values are 17.6, 6.8, 9.4, and 31.4 cm, respectively.

(18) Water available for seasonal streamflow. — The difference between weighted adjusted seasonal ET and seasonal precipitation is water available for seasonal streamflow. The respective values are 5.7, 68.4, 51.1, and −4.4 cm for fall, winter, spring, and summer, respectively.

(19) Annual ET. — The sum of weighted adjusted seasonal ET values [col.(17)] is annual ET. This is 65.2 cm.

(20) Water available for annual streamflow. — The sum of column (18), seasonal streamflow, is equal to water available for annual streamflow. This is 120.8 cm.

Flow Duration Curve Development—Existing Conditions

Step 3. — The third step in the hydrologic evaluation is to estimate the flow duration curve for the existing condition. The necessary steps outlined in worksheet III.3 are detailed below. (Numbers in parentheses refer to the items or columns on the worksheet.)

(1), (2). — Same as worksheet III.1.

(3) Water available for annual streamflow — existing condition. — This value has been calculated in worksheet III.1, item (20), to be 104.9 cm.

(4) Annual flow from duration curve for hydrologic region. — Figure III.22 gives the annual flow for watersheds in hydrologic region 2 as 72.0 cm using 11 points to calculate the area beneath the curve.

(5) Adjustment ratio. — Estimated water available for annual streamflow divided by flow, represented by the flow duration curve, equals the adjustment ratio. The adjustment ratio is rounded to the third decimal place and used to correct the given flow duration curve to equal the expected yield. For Grits Creek, it is:

$$\frac{104.9}{72.0} = 1.457$$

(6) Point number. — This is the numerical order of points used to define the flow duration curve.

(7) Percent of time flow is equaled or exceeded. — These values are read at equidistant intervals along the X-axis of figure III.22. The interval is a function of the number of desired points [i.e., if 11 points are used, the interval is 100/(11-1)].

(8) Regional flow. — These are the Y-axis values of figure III.22 corresponding to the X-axis values in column (7). This column is not necessary if a flow duration curve for the existing condition is available.

(9) Existing potential flow. — Regional flow [col. (8)] is multiplied by the adjustment ratio [item (5)] to give the existing potential streamflow. If a flow duration curve for the existing condition is available, no correction is necessary. Column (9) is plotted versus column (2) to yield the flow duration curve for the existing condition (fig. VIII.3).

(10) Existing potential flow (cfs). — Conversion of cm/7 days to cubic feet per second (cfs) is accomplished by multiplying column (7) x area (acres) x 0.002363 for 7-day intervals.

Flow Duration Curve Development—After Proposed Silvicultural Activity

Step 4. — The final step in the hydrologic evaluation of Grits Creek is to estimate the 7-day flow duration curve for conditions after the proposed silvicultural activity has been conducted. The necessary steps outlined in worksheet III.4 are detailed as follows. (Numbers in parentheses refer to the items or columns on the worksheet.)

(1), (2). — Same as worksheet III.2.

(3) Watershed aspect code. — The dominant aspect of Grits Creek is southwest. Hydrologic characteristics dictate that, for the purposes of flow duration curve calculation, an aspect of west be assigned a code of zero for the watershed (this eliminates the aspect adjustment).

(4) Existing condition LAI. — Existing LAI has already been given as 6.

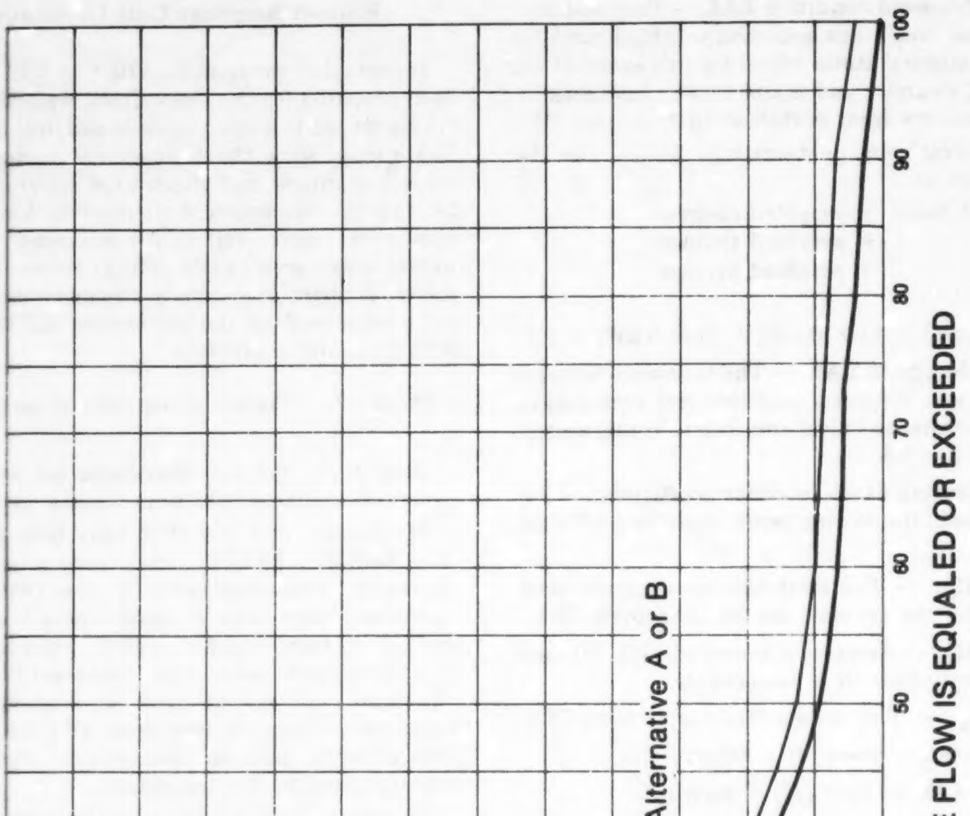

Figure VIII.3.—Annual flow duration curves for existing and alternative A or B conditions, Grits Creek watershed.

(5) Proposed condition LAI. — Proposed condition leaf area index is an area weighted index for the silvicultural states which for this example are forested, clearcut, and thinned areas. Leaf area index values are from worksheet III.2, column (13).

The weighted post-activity index can be calculated as:

weighted forest + weighted clearcut
+ weighted thinned
= weighted average

or

$(6 \times 0.236) + (2 \times 0.506) + (3 \times 0.258) = 3.2$

(6) Change in LAI. — The difference between existing and proposed condition leaf area indices yields the change in leaf area index. In this case, it is $6 - 3.2 = 2.8$.

(7) Rooting depth modifier coefficient. — For Grits Creek, the rooting depth modifier coefficient is 1.

(8)-(12). — The least squares equation coefficients for the example are found in table III.4.

(13)-(15). — Same as columns (6), (7), (9), and (10) of worksheet III.3, respectively.

(16) b_o . — This is item (8) found in table III.4.

(17) b_1Q_i. — Item (9) × column (15).

(18) b_2CD. — Item (10) × item (6).

(19) b_3AS. — Item (11) × item (3).

(20) b_4RD. — Item (12) × item (7).

(21) ΔQ_i. — Sum of columns (16), (17), (18), (19), and (20).

(22) $Q_i + \Delta Q_i$. — Column (15) + column (21).

(23) $Q_i + \Delta Q_i$ (cfs). — Column (22) x area (acreas) x 0.002363 for 7-day intervals. This is the predicted flow duration curve for the proposed silvicultural activity when plotted against column (14) (fig. VII.3).

SURFACE EROSION ANALYSIS

The quantity of surface eroded material delivered to stream channels from sites disturbed by the proposed silvicultural activities is estimated in two stages. First, the quantity of material that may be made available from a disturbed site is estimated using the Modified Soil Loss Equation (MSLE). Second, a sediment delivery index (SD_I) is estimated. When this is applied to the estimated quantity of surface eroded material available, an estimate of the quantity of material that may enter a stream channel is obtained.

Erosion Response Unit Delineation

Topographic maps (figs. VIII.4 to VIII.7) have been prepared for the Grits Creek watershed, following steps 1 through 7 as discussed in chapter IV. These maps show the drainage net, hydrographic areas, soil groups, and silvicultural activities. Road locations for management alternatives A and B are shown in figure VIII.1. An enlarged map of hydrographic area 13 (fig. VIII.8) shows the composite of cutting units, roads, stream channels, and soil groups used for the soil erosion and sediment delivery example problem.

Steps 1-7. — Prepare topographic maps (ch. IV).

Step 8. — Set up worksheets for estimating potential sediment load from surface erosion.

Worksheets IV.1 and IV.2, have been prepared with field data for Grits Creek management alternative A. Individual soils in the Grits Creek watershed have been grouped where there exist similar texture, organic matter, structure, and permeability characteristics. Worksheet IV.1 shows the three soil groups used for surface erosion evaluation. Data on worksheet IV.1 should not change when different management alternatives are evaluated for the watershed.

Worksheet IV.2 displays various types of data needed for evaluating the effects of management alternative A for Grits Creek watershed, hydrographic area 13. Individual erosion response units are identified and listed. A different erosion response unit is created for each change in management activity, each design change for a given activity (e.g., a road change from a cut-and-fill design to a complete fill for a stream crossing), or each change in environmental parameters affecting erosion (e.g., an change in soil characteristics).

Worksheet IV.3 is a summary of the values used in the MSLE and sediment delivery index for erosion response units in hydrographic area 13 of the Grits Creek watershed. The values for both management alternatives are obtained using the steps and discussions which follow. Only values for alternative A are used to illustrate methods for solving the equations, however, values for alternative B are similarly determined.

Step 9. — List each erosion source area and number by erosion response unit.

For the Grits Creek watershed, the response units have been coded as follows. The treatment types are selection cuts (SC), clearcuts (CC), and

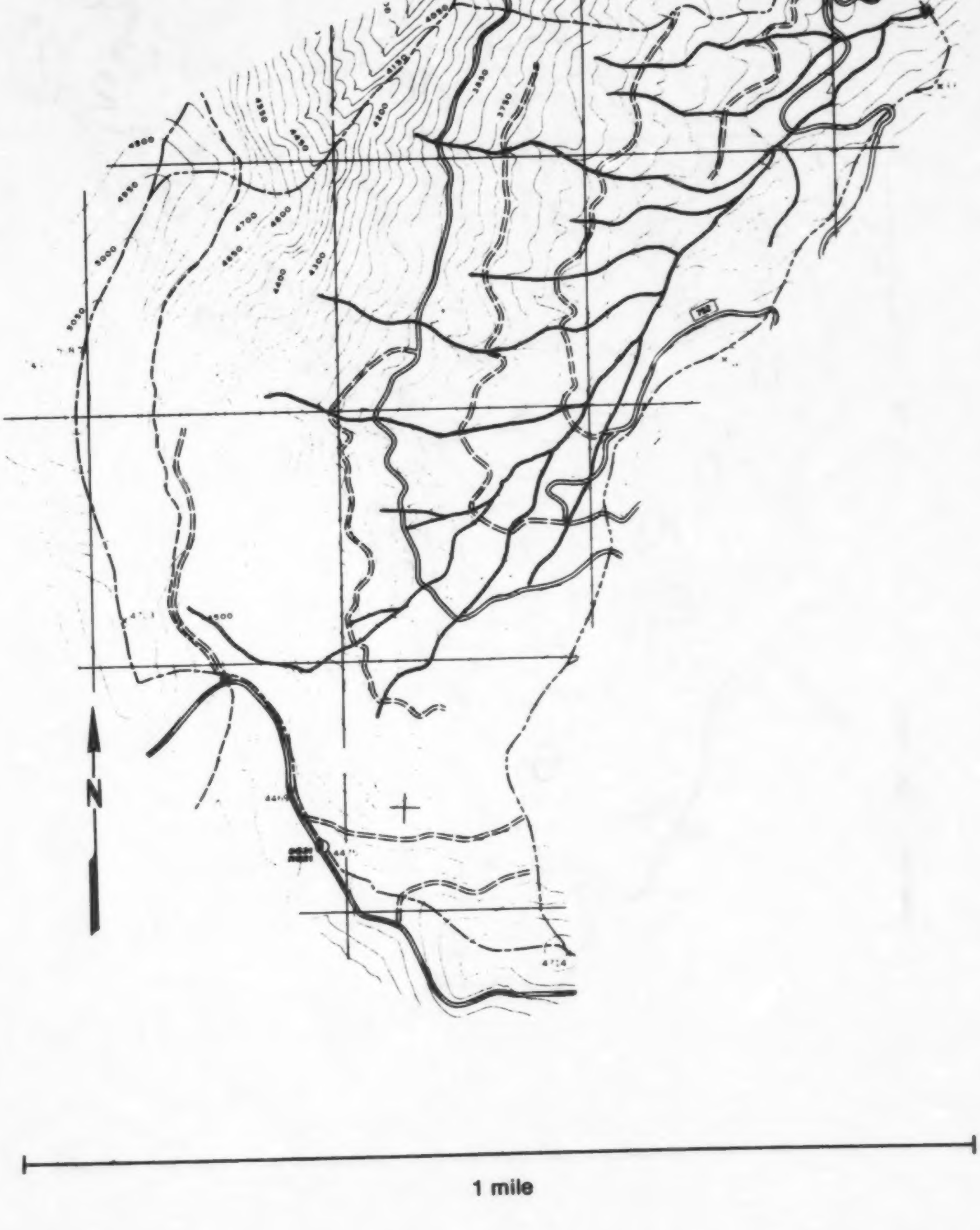

Figure VIII.4.—Drainage net, Grits Creek watershed.

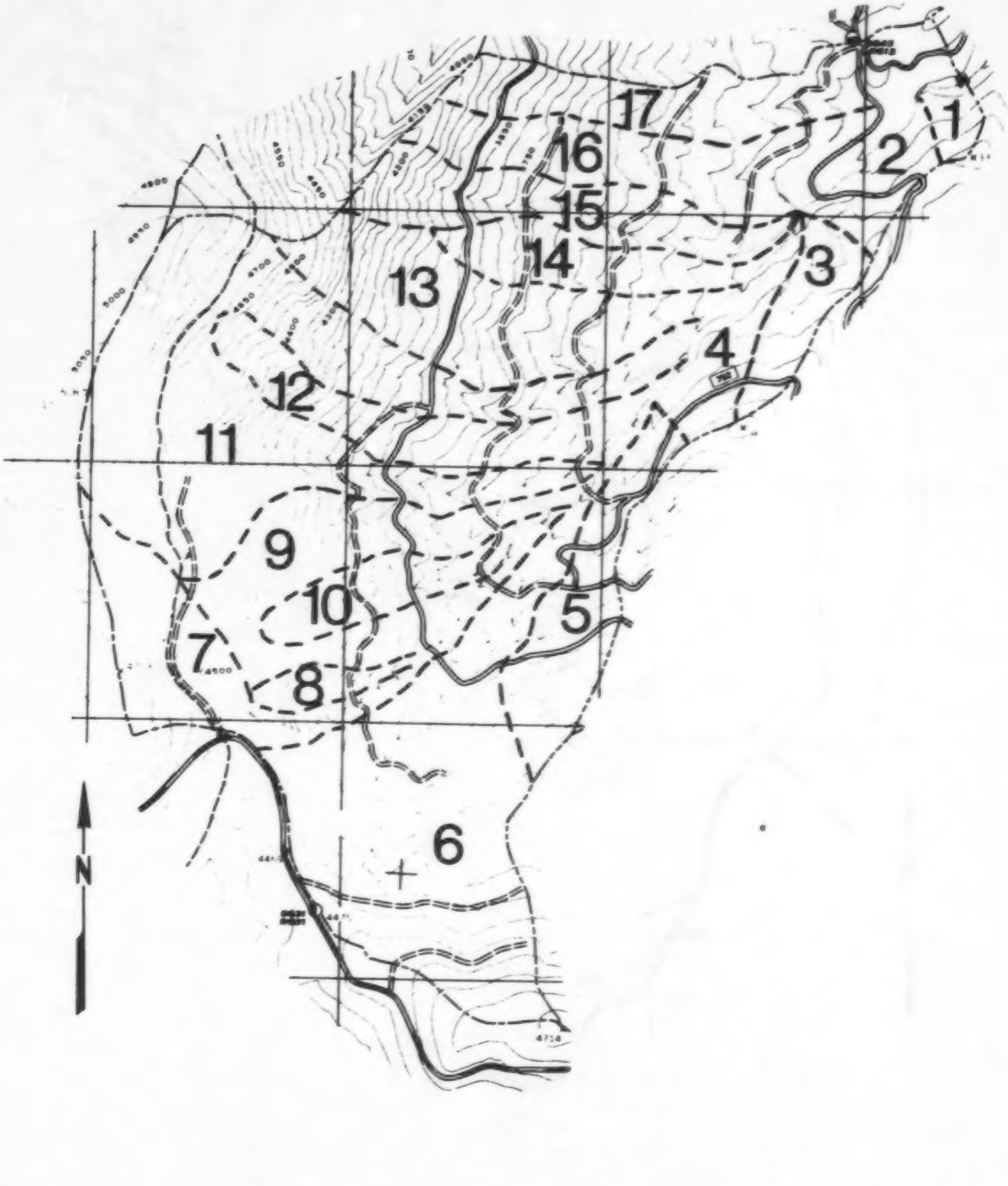

Figure VIII.5.—Hydrographic areas, Grits Creek watershed.

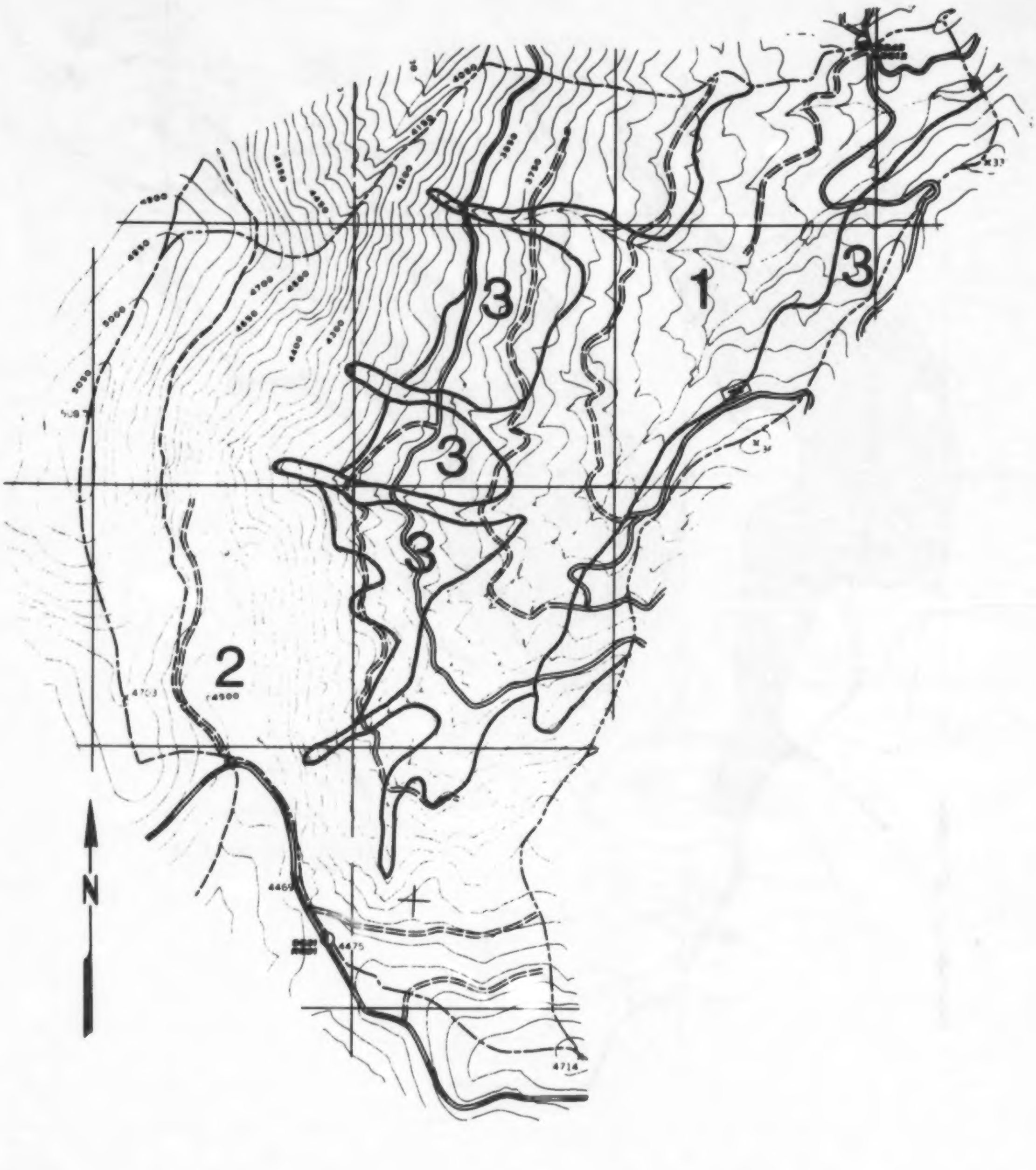

Figure VIII.6.—Soil groups, Grits Creek watershed.

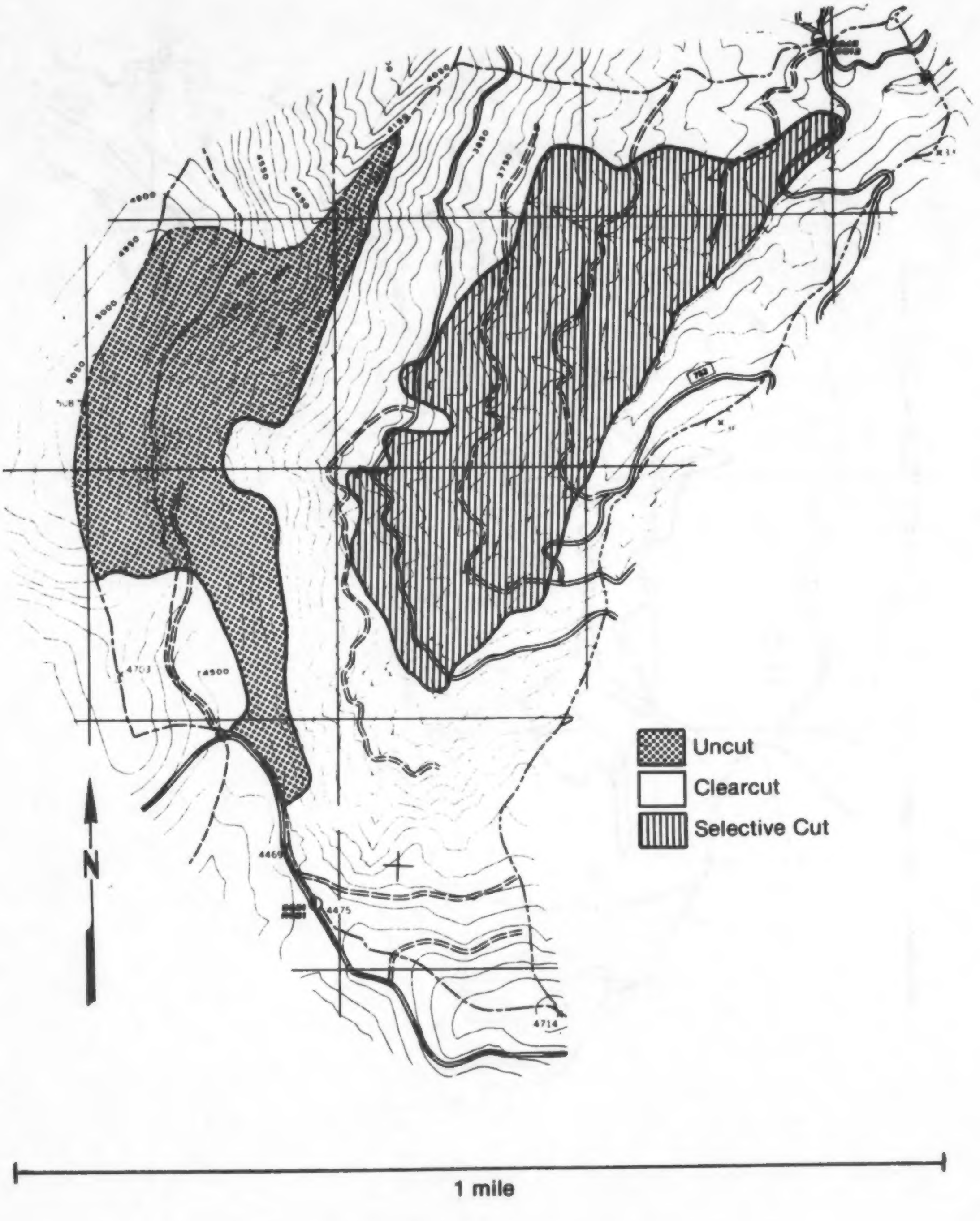

Figure VIII.7.—Silvicultural treatments, Grits Creek watershed.

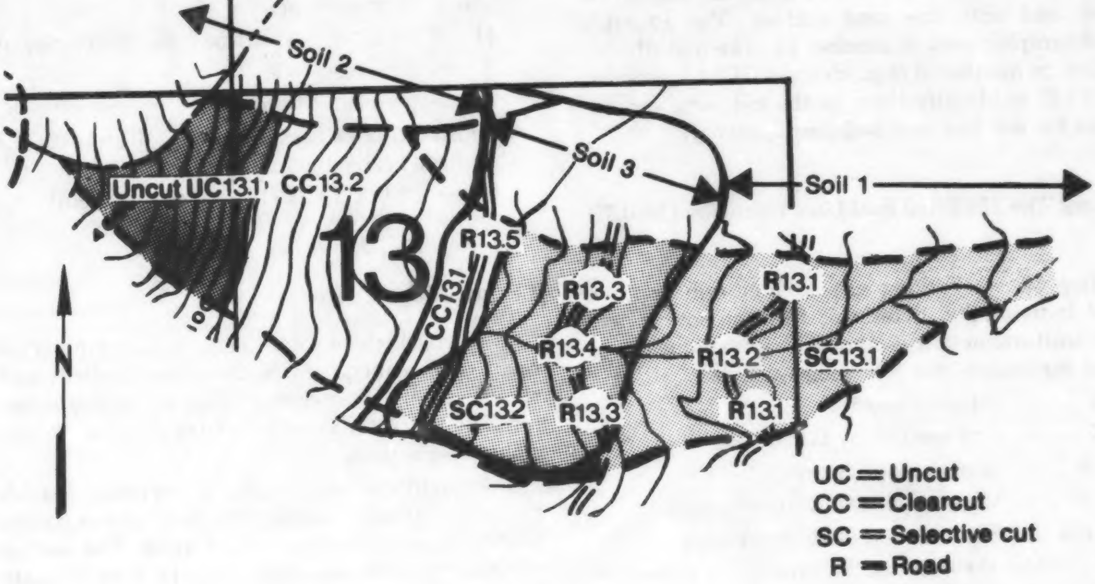

Figure VIII.8.—Enlargement of example hydrographic area showing individual erosion response units.

roads (R). There are no landings, because logs will be yarded to various locations along the side of the road and onto the road surface. The example hydrographic area is number 13. The disturbance types are numbered (e.g., clearcut CC13.1, clearcut CC13.2) to identify them in the following evaluations for soil loss and sediment delivery.

Using The Modified Soil Loss Equation (MSLE)

Step 10. — Working with each erosion response unit individually, determine for each source area (silvicultural activities and roads) the values to be used for each of the following variables:

R — Rainfall factor
K — Soil erodibility factor
LS — Length-slope factor
VM — Vegetation-management factor
Area — Surface area of response unit

Values for these factors are entered on worksheet IV.3 using the following procedures.

Rainfall Factor

For the Grits Creek area, R = 300 (fig. IV.2.) This R value is the same over the entire Grits Creek area and will be used for all erosion response units and both management alternatives.

Soil Erodibility Factor

The K value can be estimated using the nomograph in figure IV.3, or by using equation IV.4. The data for soil group 2 needed to compute the K value using equation IV.4 are found on worksheet IV.1. K must be determined for both topsoil and subsoil. For disturbances which enter the subsoil, such as roads, the subsoil value of K must be used.

Application of the equation to determine the K factor is shown in the following example for topsoil in soil group 2. Because of inflections in the family of curves on the nomograph (fig. IV.3) for percent sand, the equation cannot be used when silt plus very fine sand exceeds 70 percent.

$$K = (2.1 \times 10^{-6})\ (12 - Om)\ M^{1.14} + 0.0325\ (S-2) + 0.025\ (P-3) \qquad (IV.4)$$

where:

Om = % organic matter
M = (% silt + % very fine sand) (100 − % clay)
S = structure code
P = permeability code

Substituting values for topsoil (soil group 2) from worksheet IV.1 into equation IV.4:

$$K = (2.1 \times 10^{-6})\ (12-4)\ [40\ (100-20)]^{1.14} + 0.0325\ (2-2) + 0.025\ (2-3)$$

$$K = 0.14$$

Length-Slope Factor

The length-slope factor, LS, is a combination factor which incorporates the slope gradient and the length of the eroding surface into a single factor. The LS factor must be estimated for each erosion response unit.

Two methods may be used to estimate the LS factor on straight slopes. One is to use equation IV.8 to derive the estimated LS value. The second method utilizes a nomograph (fig. IV.4) to estimate the LS value.

The cutting units (SC13.1, SC13.2, CC13.1, and CC13.2) are each different in regard to slope gradient and length. Therefore, LS for each cutting unit must be evaluated separately. Using equation IV.8 and data from worksheet IV.2, the LS value for CC13.1 is calculated as follows for slope length λ = 132 feet and slope gradient s = 12 percent.

$$LS = \left(\frac{\lambda}{72.6}\right)^{m} \left(\frac{0.43 + 0.30s + 0.043s^2}{6.613}\right) \left(\frac{10{,}000}{10{,}000 + s^2}\right) \qquad (IV.8)$$

where:

λ = slope length, in feet
s = slope gradient, in percent
m = an exponent based on slope gradient from equation IV.6

Using data from worksheet IV.2:

$$LS = \left(\frac{132}{72.6}\right)^{0.5} \left(\frac{0.43 + 0.30(12) + 0.043(12)^2}{6.613}\right) \left(\frac{10{,}000}{10{,}000 + (12)^2}\right)$$

$$LS = 2.05$$

Similar calculations are made for erosion response units SC13.1, SC13.2, and CC13.2.

To compute the length-slope value for the road sections (R13.1, R13.2, and R13.3), the equation for irregular slopes is used in this example. An alternative method using graphs (figs. IV.5 and IV.6) is discussed in chapter IV. The LS equation for roads is:

$$LS = \frac{1}{\lambda_e} \cdot \sum_{j=1}^{n} \left[\left(\frac{S_j \lambda_j^{m+1}}{72.6^m} - \frac{S_j \lambda_{j-1}^{m+1}}{72.6^m} \right) \left(\frac{10{,}000}{10{,}000 + s_j^2} \right) \right] \qquad \text{(IV.9)}$$

The number of calculations can be reduced by simplifying equation IV.9 to:

$$LS = \frac{1}{\lambda_e} \cdot \sum_{j=1}^{n} \left[S_j \left(\frac{\lambda_j^{m+1} - \lambda_{j-1}^{m+1}}{72.6^m} \right) \left(\frac{10{,}000}{10{,}000 + s_j^2} \right) \right] \qquad \text{(IV.9.1)}$$

where:

λ_e = entire length of a slope, in feet

λ_j = length of slope to lower edge of jth segment, in feet

j = slope segment

s_j = slope gradient, in percent

S_j = dimensionless slope steepness factor for segment j defined by

$$S_j = (0.043 s_j^2 + 0.30 s_j + 0.43)/6.613$$

m = an exponent based on slope gradient

n = total number of slope segments

For the road R13.1, using values in worksheet IV.2 and assuming that no sediment is deposited on the road surface, the computations are as follow:

Slope segment 1 (cut)

λ_1 = 3.5 feet

λ_{1-1} = 0.0 feet (there are no preceding slope segments, hence length is 0.0 ft)

s = 170%

m = 0.6 (for slopes on construction sites; see eq. IV.6)

$$S_1 = \frac{0.043s^2 + 0.30s + 0.43}{6.613}$$

substituting for s:

$$S_1 = \frac{0.043(170)^2 + 0.30(170) + 0.43}{6.613} = 196$$

Substituting S, λ, and m values for j=1 into equation IV.9.1 to the right side of the summation sign gives:

$$196 \left(\frac{(3.5)^{1.6} - (0)^{1.6}}{(72.6)^{0.6}} \right) \left(\frac{10{,}000}{10{,}000 + (170)^2} \right)$$

$$= 28.59$$

Slope segment 2 (roadbed)

λ_2 = 3.5 + 12.0 = 15.5 feet

λ_{2-1} = 3.5 feet

s = 1%

m = 0.6 (for slopes on construction sites)

$$S_2 = \frac{0.043s^2 + 0.30s + 0.43}{6.613}$$

substituting for s:

$$S_2 = \frac{0.043(1)^2 + 0.30(1) + 0.43}{6.613} = 0.117$$

Substituting S, λ, and m values for j=2 into equation IV.9.1 to the right side of the summation sign gives:

$$0.117 \left(\frac{(15.5)^{1.6} - (3.5)^{1.6}}{(72.6)^{0.6}} \right) \left(\frac{10{,}000}{10{,}000 + (1)^2} \right)$$

$$= 0.65$$

Slope segment 3 (fill)

λ_3 = 3.5 + 12.0 + 4.5 = 20.0 feet

λ_{3-1} = 3.5 + 12.0 = 15.5 feet

s = 100%

m = 0.6 (for slopes on construction sites)

$$S_3 = \frac{0.043s^2 + 0.30s + 0.43}{6.613}$$

substituting for s:

$$S_3 = \frac{0.043(100)^2 + 0.30(100) + 0.43}{6.613} = 69.6$$

Substituting S, λ, and m values for $j=3$ into equation IV.9.1 to the right of the summation sign gives: gives:

$$69.6\left(\frac{(20.0)^{1.6} - (15.5)^{1.6}}{(72.6)^{0.6}}\right)\left(\frac{10{,}000}{10{,}000 + (100)^2}\right)$$

$$= 107.54$$

Solving the entire equation IV.9.1, using the calculated values where:

$$\lambda_e = 3.5 + 12.0 + 4.5 = 20 \text{ feet}$$

then:

$$LS = \frac{1}{\lambda_e}(\text{slope seg. } 1 + \text{slope seg. } 2 + \text{slope seg. } 3)$$

$$= \frac{1}{20}(28.59 + 0.65 + 107.54)$$

$$= 6.84$$

A similar LS calculation is made for road R13.5. Road R13.2, however, is a fill across a stream channel and becomes two problems, each with two segments. Each segment starts at the middle of the road surface, and the second segment includes one of the fill slopes. An average LS value from both halves of the road is used as the final LS value (1.81) to be entered on worksheet IV.3.

Vegetation-Management Factor

The vegetation-management factor (VM) is used to evaluate effects of cover and land management practices on surface erosion over the entire slope length used for the LS factor. VM factors are determined for all cutting units and roads.

(1) Cutting units. — Worksheet IV.2 has the field data used for calculating a VM factor for the clearcut units (CC13.1 and CC13.2) and the selective cut units (SC13.1 and SC13.2). Example calculations are shown for clearcut CC13.1. The cutting unit is divided into two areas based on the presence or absence of logging residues. A ground cover of slash and other surface residues covers 55 percent of the unit (wksht. IV.2). The remaining 45 percent is scattered with open areas of bare soil and soil duff mixtures averaging 15 feet in diameter.[2]

In the 55 percent of the area (CC13.1) covered by slash and other surface residues, fine tree roots are uniformly distributed over 99 percent of the area. In the 45 percent of clearcut area CC13.1 that is open, fine tree roots are uniformly distributed over 80 percent of the open area. All of the overstory and understory canopy has been removed.

Using worksheet IV.4, first, enter percent area as 0.55 and 0.45 for area covered by residues and open area, respectively. Separate calculations are made for the logging residue areas and open areas.

Second, the logging slash represents the mulch and close growing vegetation. Because slash varies in density, assume that small openings a few inches in diameter exist over 40 percent of the surface. from figure IV. 9, the 60 percent cover provides a mulch factor of 0.25. The 45 percent of CC13.1 that is open is assumed to have 45 percent of the surface protected by widely scattered slash. Using figure IV.9, a mulch factor of 0.35 is found for this situation.

Third, zero canopy cover gives a canopy factor of 1.0 for both areas (fig. IV.8).

Fourth, evaluate the role of fine roots that are remaining in the soil. The slash area has fine roots uniformly distributed over 99 percent of its surface area and figure IV. 10 shows a corresponding fine root factor of 0.10. The open area has fine roots uniformly distributed over 80 percent of its area; figure IV.10 gives a corresponding value of 0.12.

Fifth, determine if the open areas are connected with each other such that water can flow downslope from one to another (ch. IV). In this example, the open areas are isolated from each other by bands of logging residue, requiring the use of a sediment filter strip factor of 0.5 (see "Sediment Filter Strips" section of "Chapter IV: Surface Erosion"). If these sediment filter strips did not exist, a factor of 1.0 would be used.

Sixth, using worksheet IV.4, multiply the VM subfactors for logging residue (0.55) (0.25) (1.0) (0.10) = 0.0138. Similarly for the open area: (0.45) (0.35) (0.12) (0.5) = 0.0095. The overall VM factor for CC13.1 is the sum of the two factors: (0.0138) + (0.0095) = 0.023.

Similar calculations are made for CC.13.2, SC13.1, and SC13.2. Values are shown on worksheet IV.4.

(2) Landings. — No landings are planned for Grits Creek.

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[2] *Information about the amount of residue is often expressed in tons per acre. Maxwell and Ward (1976) have published photos and tables for parts of Oregon and Washington which relate visual appearance of a site with the volume of residue and amount of ground cover.*

(3) Roads. — The VM factor must represent two conditions on the road areas: (1) the road running surface, and (2) the cut-and-fill banks that are needed (fig. IV.7).

The average width of disturbed surface for road R.13.1 is 1.8 + 12.0 + 3.1 = 16.9 ft

Running surface $\frac{12.0 \text{ ft}}{16.9 \text{ ft}} = 0.7101$ = fraction of total width

Cut slope $\frac{1.8 \text{ ft}}{16.9 \text{ ft}}$ [illegible] 0.1065 = fraction of total width

Fill slope $\frac{3.1 \text{ ft}}{16.9 \text{ ft}} = 0.1834$ = fraction of total width

The weighted VM factor for the road R13.1 is calculated and shown on worksheet IV.6. Similar calculations have been made for roads R13.1 and R13.5.

Surface Area Of Response Unit

Total surface area within each treatment unit—clearcuts, selective cuts, and roads—is given in worksheet IV.2 and is entered on worksheet IV.3. All other MSLE factors are also entered into worksheet IV.3. Total potential onsite soil loss is computed by multiplying all the MSLE factors on worksheet IV.3.

Sediment Delivery

Step 12. — The computed potential sediment is delivered to the closest stream channel using a sediment delivery index (SD_I). Worksheet IV. 7 is used to organize the data for each erosion response unit for each factor shown on the stiff diagram (fig. VIII.9).

1. Water availability for sediment delivery is calculated using equation IV.12 for each erosion response unit:

$$F = CRL \qquad \text{(IV.12)}$$

where:

F = available water (ft³/sec)

R = [1 year, 15 minute storm (in/hr)] - [soil infiltration rate (in/hr)]

L = [slope length distance of disturbance (ft)] + [slope length from disturbance to stream (ft)]

$$C = 231 \times 10^{-5} \ \frac{\text{ft}^2 \text{ hr}}{\text{in sec}}$$

The infiltration rate used in determining the R factor is the maximum rate at which water could enter a soil. In actual situations, the water entry rate will usually be somewhat lower than the infiltration rate and can be based on the soil permeability with consideration for effects of various management practices.

Using data from worksheet IV.2 and footnotes from worksheet IV.7, the calculations for CC13.1 are:

$$F = \left(2.31 \times 10^{-5} \ \frac{\text{ft}^2 \text{ hr}}{\text{in sec}}\right) (2.5 \text{ in/hr} - 2.0 \text{ in/hr})$$

$$(132 \text{ ft} + 0 \text{ ft})$$

$$F = 0.0015 \text{ ft}^3/\text{sec}$$

2. Texture of eroded material is based on the amount of very fine sand, silt, and clay shown on worksheet IV.1. For this case, it has been assumed that one-half of the clay will form stable aggregates, with the remaining clay influencing the sediment delivery index. For soil group 3 topsoil, the following calculations were made:

$$\text{texture of eroded material} = \frac{\% \text{ clay}}{2} + \% \text{ silt} + \% \text{ very fine sand}$$

$$= \frac{25}{2} + 26 + 19$$

$$= 57$$

3. Ground cover is the percentage of the soil surface with vegetative residues and stems in direct contact with the soil. The ground cover on the area between a disturbance and a stream channel is determined from field observations and used for the sediment delivery index. For CC13.1, 53 percent is shown on worksheet IV.2 for ground cover.
4. Slope shape is a subjective evaluation of shapes between convex and concave. From worksheet IV.2, for CC13.1 the slope shape is concave.
5. Distance is the slope length from the edge of a disturbance to a stream channel. For CC13.1 (wksht. IV.2) the distance is 0.0, because the disturbance extends to the channel.

6. Surface roughness is a subjective evaluation of soil surface microrelief ranging from smooth to moderately rough. Worksheet IV.2 shows a moderate surface roughness for CC13.1.
7. Slope gradient is the percent slope between the lower boundary of the disturbed area and the stream channel. Worksheet IV.2 shows a gradient of 12 percent for the disturbed area.
8. Site specific is an optional factor that was not used in this example. See chapter IV for more discussion of this factor.

The tabulated factors for CC13.1 (wksht IV.7) are plotted on the appropriate vectors of the stiff diagram (fig. VIII.9) as discussed in chapter IV. Use any one of several methods to determine the area bounded by the irregular polygon that is created when points on the stiff diagram are joined. The area of the polygon for this example is 107.9 square units. The stiff diagram has 784 square units. The percentage of the total area enclosed by the polygon is:

$$\left(\frac{107.9}{784}\right)(100) = 13.8\%$$

Entering the X-axis of the probit curve (fig. IV.23) with 13.8 results in a sediment delivery index (SD_I) of 0.02. This is the estimated fraction of eroded material that could be delivered from this disturbance to the stream channel.

Step 13. — Find the estimated quantity of sediment (tons/yr) delivered to a stream channel by multiplying surface soil loss by the sediment delivery index (wksht. IV.3) for each erosion response unit.

Step 14. — Using worksheet IV.8, tabulate quantities of delivered sediment (tons/yr) for each hydrographic area by the erosion source. When completed, this table provides a summary of surface erosion sources and estimated quantities of sediment production from each hydrographic area.

Step 15. — Totals and percentages are shown on worksheets IV.8. The total quantity of delivered material is entered on table VIII.2.

Differences Between Management Alternatives

A second set of worksheets IV.2 to IV.8 show data and results of calculations for Grits Creek alternative B. Specific differences between alternatives A and B can be seen by comparing values in the two sets of worksheets. For example, alternative B results in more of the total surface area covered with residues and mulch and more fine roots. The results of these effects are shown on worksheet IV.3 as the VM factor. For alternative A, CC13.1, VM = 0.023 as compared to VM = 0.003 for alternative B, CC13.1. The lower VM for alternative B indicates that vegetative materials on the ground are more effective in reducing erosion than they are in alternative A. There are similar differences in the VM factor for other cutting units and roads. The net effect is a total of 34.2 tons/yr for alternative A and 6.7 tons/yr for alternative B (wksht. IV.8).

TOTAL POTENTIAL SEDIMENT ANALYSIS

The following steps are diagrammatically shown in figure IV.9.

Step 1. — The stream reach characterization will be obtained on the lower reaches of the third-order stream channel on main Grits Creek.

Step 2. — See figure VIII.3, flow duration curve for Grits Creek.

Suspended Sediment Calculation

Step 3. — Establish suspended sediment rating curve.

a. Obtain sediment rating curve from the measured depth integrated suspended sediment sampling and concurrent stream discharge measurements. A plot of these figures is shown in figure VIII.10.
b. $\log Y = 0.61 + 0.96 \log Q$
   $r^2 = 0.98$
c. Channel stability rating: fair. The analysis outlined by Pfankuch (1975) was used to obtain this value. A correlation between the various ranges in stream channel stability and sediment rating curves as explained in appendix VI.B was obtained for the Grits Creek watershed. Figure VIII.11 indicates the channel stability threshold limit which is the upper limit for a fair rating.

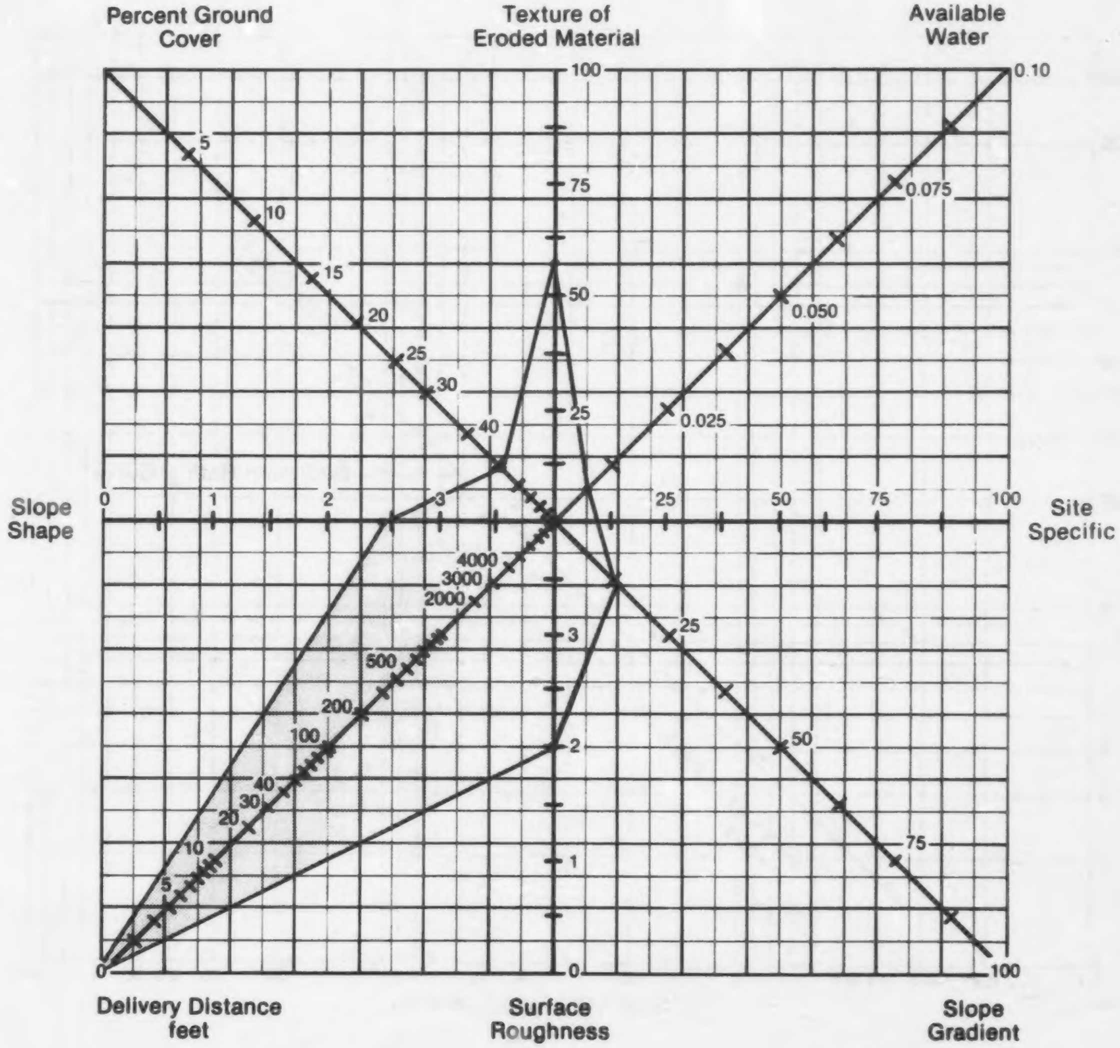

Figure VIII.9.—Stiff diagram for alternative A CC3.1, Grits Creek watershed.

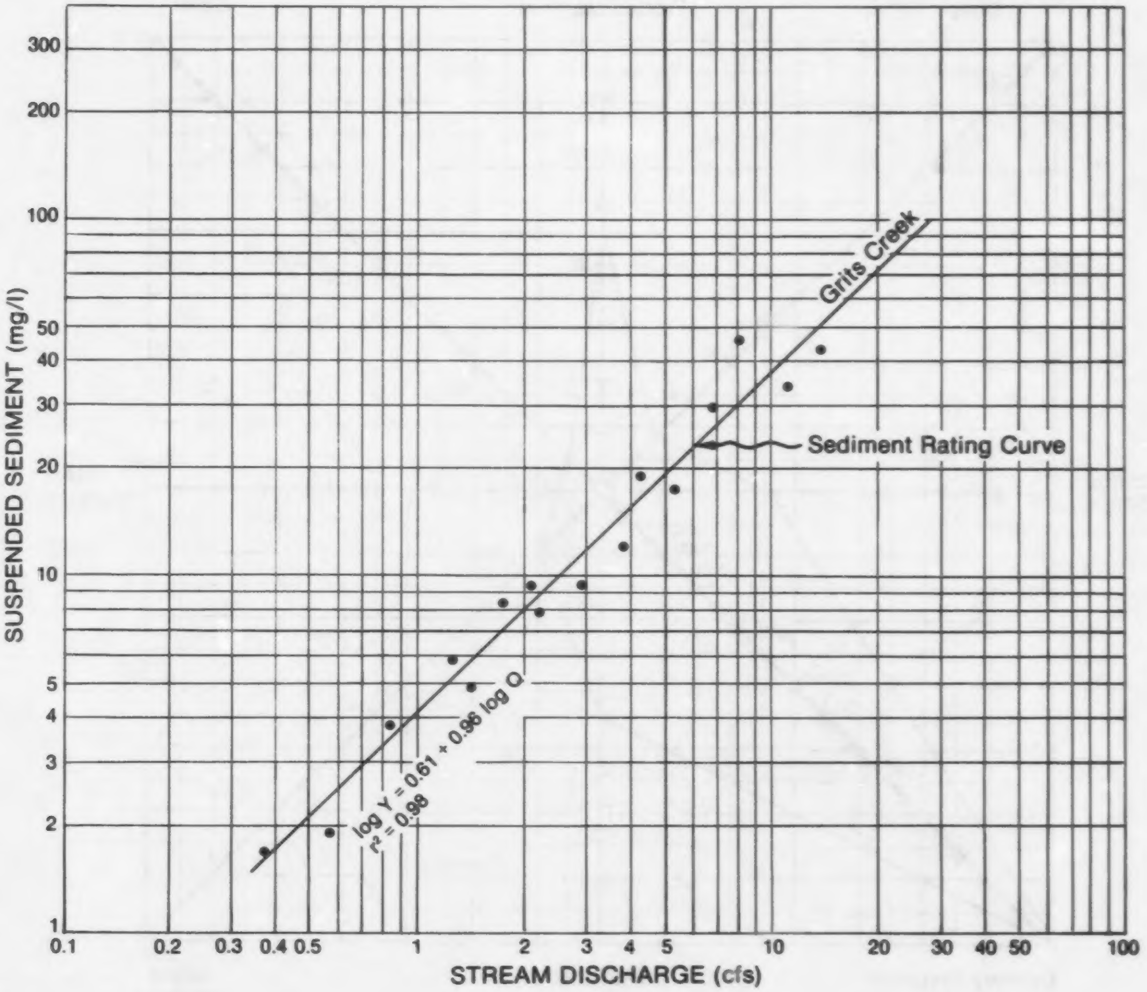

Figure VIII.10.—Sediment rating curve, Grits Creek watershed.

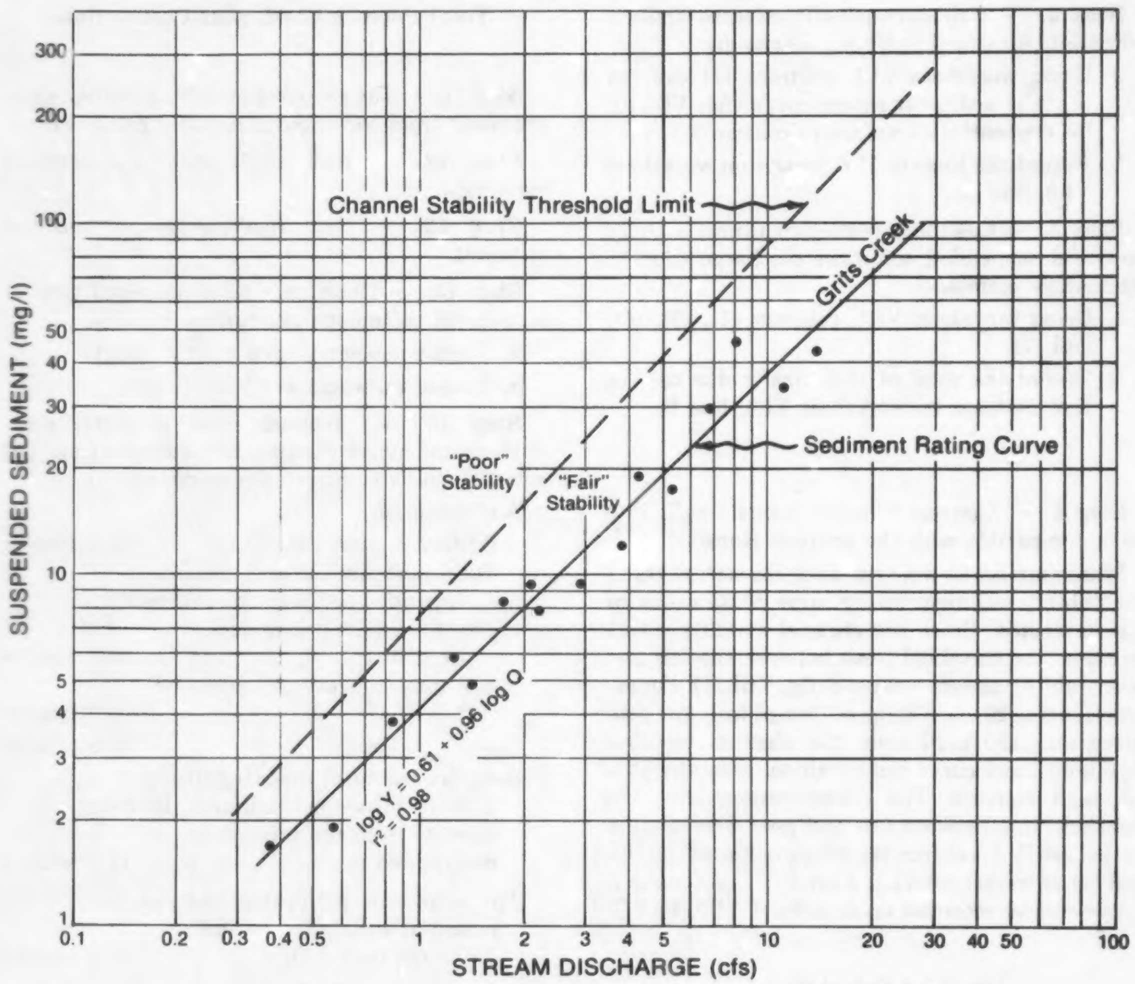

Figure VIII.11.—Channel stability threshold limits in relationship to the sediment rating curve, Grits Creek watershed.

Step 4. — Calculate pre-silvicultural activity potential suspended sediment discharge.

a. Using worksheet VI.1, columns (1) through (4). Use sediment rating curve (fig. VIII.10) for concentration values in column 3.

b. Record the total of 11.6 tons/yr on worksheet VI.3, line A.

Step 5. — Calculate post-silvicultural activity potential suspended sediment discharge (due to streamflow increases).

a. Using worksheet VI.1, columns (1), (5), (6), and (7).

b. Record the total of 19.6 tons/yr due only to flow increase on worksheet VI.3, line B.

Step 6. — Convert selected limits (mg/l) into units compatible with the analysis (tons/yr).

Maximum limits were set using the stream channel stability-sediment rating curve relationship for the watershed. Since the channel stability rating was fair, the threshold limit between the fair and poor stability classes was used (fig. VIII.11). For example, using 20 cfs, a value of 70 mg/l from the poor curve and 190 mg/l from the channel stability threshold limit curve are obtained, resulting in a 120 mg/l increase. The concentrations from the threshold line between fair and poor were used in worksheet IV.1, column (8). Using columns (2), (8), and (9) of worksheet VI.1, a total of 25.5 tons/yr is obtained and recorded on worksheet VI.3, line C.

Bedload Calculation

Step 7. — Bedload measurements were taken, but because of the heavily armored channel, no bedload was caught in a Helley-Smith sampler. Bedload rates appear to be negligible except in the event of a flood.

Step 8. — Not applicable because no bedload material was caught in sampler.

Step 9. — Calculate pre-silvicultural activity potential sediment discharge (suspended and bedload).

a. From step 4, (suspended sediment) = 11.6 tons/yr.

b. Record on worksheet VI.3, line K.

Step 10. — Not applicable—no bedload material.

Total Potential Sediment Calculation

Step 11. — The proposed activity contributed no sediment from soil mass movement processes.

Step 12. — Not applicable—no bedload material.

Step 13. — Not applicable—no bedload material.

Step 14. — Determine total delivered tons of suspended sediment from surface erosion.

a. Surface erosion source = 34.2 tons/yr

b. Record on worksheet VI.3, line D.1.

Step 15. — Compare total potential post-silvicultural activity suspended sediment (mg/l) to selected limits (tons/yr). On worksheet VI.3:

Add totals of:

Surface erosion (line D.1)	34.2 tons/yr
Total post-silvicultural activity suspended sediment discharge due to flow related increases (line B)	19.6 tons/yr
Soil mass movement (washload) (line D.4)	0.0 tons/yr
Total	53.8 tons/yr
Subtract the total pre-silvicultural activity suspended sediment discharge (line A) from the previously determined figure	11.6 tons/yr
The remainder is the total increase in potential suspended sediment discharge (line I.1)	42.2 tons/yr
Subtract the maximum allowable increase in suspended sediment discharge (line C) from the total increase in potential suspended sediment discharge (line I.1)	25.5 tons/yr
The remainder is the net change (this may be either a positive or negative number)	+16.7 tons/yr

Step 16. — Total potential post-silvicultural activity sediment discharge—all sources:

Summation of steps 5, 10, 11, and 14.

a. Post-silvicultural activity suspended sediment (flow related increases) (step 5, wksht. VI.3, line B) = 19.6 tons/yr

b. Bedload—not applicable.

c. Soil mass movement volume —not applicable.	
d. Surface erosion (step 11, wksht. VI.3, line D.1 =	34.2 tons/yr
Total	53.8 tons/yr

Record on line L, worksheet VI.3.

Step 17. — Total potential sediment discharge increase resulting from silvicultural activity:

a. Subtract total potential pre-silvicultural activity sediment discharge (step 9) from total potential post-silvicultural activity sediment discharge (step 16)

Total post-worksheet IV.3, line L	53.8 tons/yr
Total pre-worksheet VI.3, line K	11.6 tons/yr
Total potential sediment increase	42.2 tons/yr

b. Record on worksheet VI.3, line M.

The total potential sediment increase is also recorded in table VIII.2 for management alternative A and table VIII.3 for management alternative B.

Channel Impacts

Step 18. — Not applicable to Grits Creek because direct channel impacts from debris, width constrictions, or gradient changes are not anticipated with the proposed action.

Step 19. — Not applicable.

Step 20. — Not applicable.

Step 21. — Not applicable.

TEMPERATURE ANALYSIS

Grits Creek was segmented into four reaches for temperature evaluation purposes (wksht. VII.2 and fig. VIII.12). This was necessary because of the variety of silvicultural activities—partial and clearcut—and length of stream involved—more than 1 mile from headwater to mouth. The first reach consists of an open meadow, 600 feet long, with no vegetative shade. The trees to be cut near the mouth are distant enough from the stream that they provide no shade. Therefore, the proposed silvicultural activity will not directly impact water temperature near the mouth. The partial cut area is approximately 3,800 feet along the center portion of the watershed. Since the evaluation procedure is valid for reaches up to 2,000 feet, this section of stream was divided into two reaches—a lower reach 2,000 feet long, and a middle reach of 1,800 feet. The headwater portion of the stream is in a clearcut; the upper reach is 1,000 feet long.

Following is the evaluation for each stream reach and an integration of the individual reaches to arrive at an estimated maximum daily potential temperature increase at the mouth. The analysis is the same for both management alternatives since the exposure to the stream has not changed.

Lower Reach

Computing H, Adjusted Incident Heat Load

Step 1. — Determine H (i.e., incident heat load) based upon latitude of site, critical time of year (month and day), and orientation of stream.

Step 1.1. — Select the solar ephemeris that most closely approaches the latitude of the site, 35°N (fig. VII.2).

Step 1.2. — Locate the declination in the solar ephemeris (fig. VII.2) that corresponds to the date when maximum water temperature increase is anticipated: last week August; therefore, a declination of +10°.

Step 1.3. — Once the declination, +10°, is known, determine the azimuth and solar angle for various times during the day from the solar ephemeris (fig. VII.2) and record the values in worksheet VII.1. Azimuth readings are found along the outside of the circle and are given for every 10°. Solar angle (i.e., degrees above the horizon) is indicated by the concentric circles and ranges from 0° at the outermost circle to 90° at the center of the circle. The time is indicated above the +23°27' declination line and is given in hours, solar time. Note that the time of day shown on worksheet VII.1 is given as daylight savings time (DST).

Step 1.4. — Evaluate the orientation of the sun (i.e., azimuth and angle determined in step 1.3 above) with the stream, and determine what vegetative shading effectively shades the stream. To do this, compare stream effective width with shadow length. Determine the maximum solar angle (i.e., maximum radiation influx to stream)

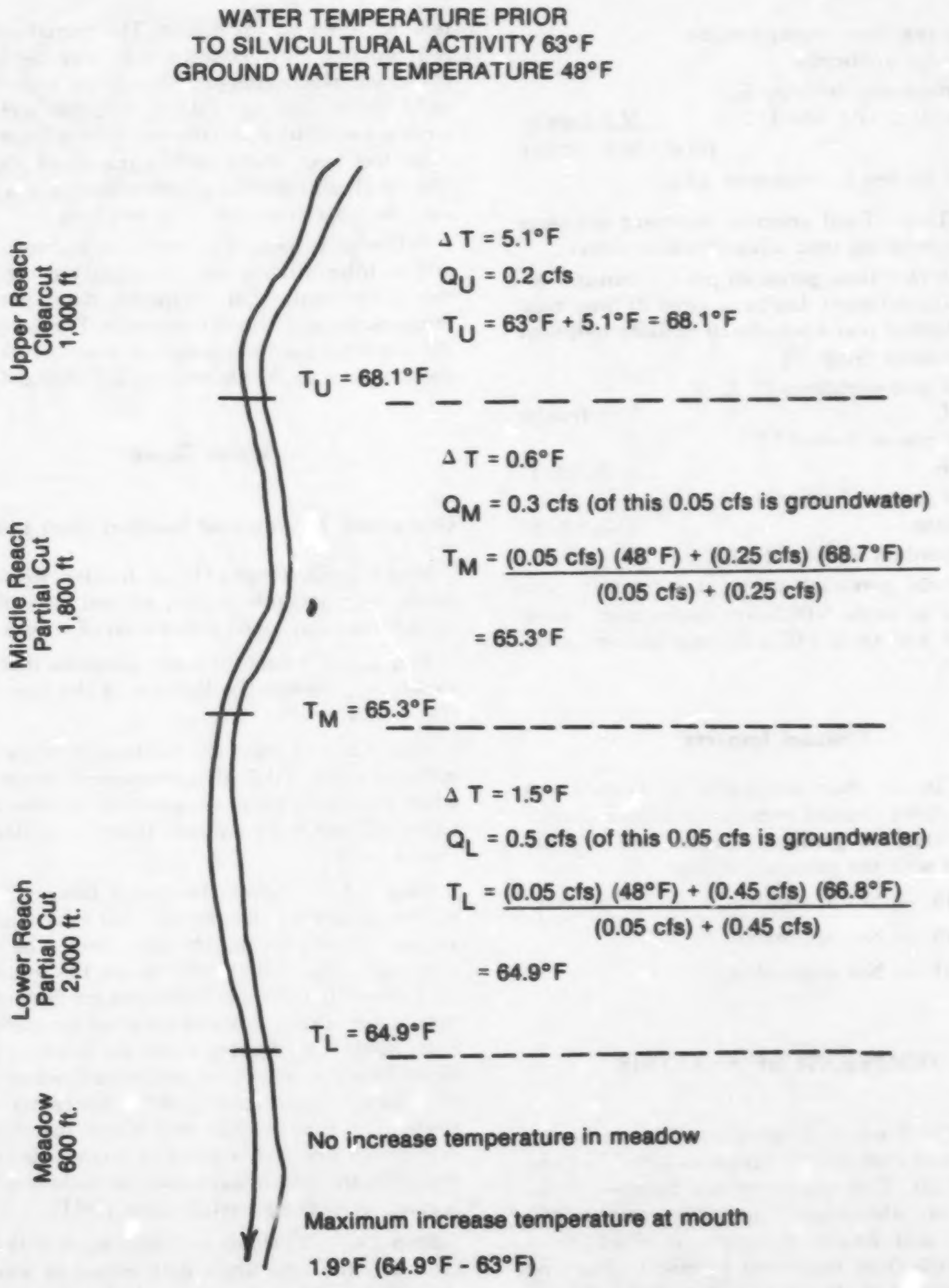
WATER TEMPERATURE PRIOR TO SILVICULTURAL ACTIVITY 63°F
GROUND WATER TEMPERATURE 48°F
Upper Reach Clearcut 1,000 ft
$\Delta T = 5.1°F$
$Q_U = 0.2$ cfs
$T_U = 63°F + 5.1°F = 68.1°F$
$T_U = 68.1°F$
Middle Reach Partial Cut 1,800 ft
$\Delta T = 0.6°F$
$Q_M = 0.3$ cfs (of this 0.05 cfs is groundwater)
$T_M = \frac{(0.05 \text{ cfs})(48°F) + (0.25 \text{ cfs})(68.7°F)}{(0.05 \text{ cfs}) + (0.25 \text{ cfs})}$
$= 65.3°F$
$T_M = 65.3°F$
Lower Reach Partial Cut 2,000 ft.
$\Delta T = 1.5°F$
$Q_L = 0.5$ cfs (of this 0.05 cfs is groundwater)
$T_L = \frac{(0.05 \text{ cfs})(48°F) + (0.45 \text{ cfs})(66.8°F)}{(0.05 \text{ cfs}) + (0.45 \text{ cfs})}$
$= 64.9°F$
$T_L = 64.9°F$
Meadow 600 ft.
No increase temperature in meadow
Maximum increase temperature at mouth
1.9°F (64.9°F - 63°F)

Figure VIII.12.—Water temperature evaluation, Grits Creek watershed.

that will occur when the stream is exposed following the silvicultural activity. Height of the existing vegetation immediately adjacent to the stream is 80 feet.

Step 1.4.1. — The direction the shadows fall across the stream will determine effective width of the stream.

Effective width is computed using the following formula:

$$EW = \frac{\text{measured average stream width}}{\text{sine} \mid \text{azimuth stream - azimuth sun} \mid} \quad \text{(VII.4)}$$

Azimuth of the particular stream is 35°. For example, at 12 p.m. (wksht. VII.1) EW would be equal to:

$$EW = \frac{4 \text{ ft}}{\text{sine} \mid 35° - 148° \mid} = 4.4 \text{ ft}$$

The absolute value of azimuth of the stream subtracted from the azimuth of the sun must be less than a 90°-angle. Should the difference exceed 90°, subtract this absolute value from 180° to obtain the correct acute angle. Then the sine is taken of this computed acute angle.

Step 1.4.2. — Shadow length is computed using the formula:

$$S = \frac{\text{height vegetation}}{\text{tangent solar angle}} \quad \text{(VII.5)}$$

For example, at 12 noon, S would be equal to:

$$S = 80 \text{ ft/tangent } 62° = 42.5 \text{ ft}$$

Summary of steps 1.4.1 and 1.4.2: The existing trees that are scheduled to be cut provide shade to the streams. The only time when trees might not shade the stream is 2:15 p.m., when the stream's effective width is infinity (sun is oriented with the stream) and the shadow length is only 46.2 feet. Therefore, removal of the vegetation would result in exposure of the water surface to increased solar radiation.

The proposed silvicultural activity would have the maximum impact on water temperature at 1 p.m. (solar noon) when the solar angle (65°) and radiation are greatest.

Step 1.5. — Topographic shading should be evaluated to determine if the water course would be shaded by topographic features. For topographic shading, the percent slope of the ground must exceed the percent slope of the solar angle, (i.e., tangent of the solar angle). In this case,

side slope east = 53%
side slope west = 50%

Solar angle expressed as percent for:

8 a.m. DST	= 32%
9 a.m.	= 58%
1 p.m.	= 214%
5 p.m.	= 58%
6 p.m.	= 32%

Therefore, topographic shading is possible before 9 a.m. and after 5 p.m. There is no topographic shading the rest of the day.

Step 1.6. — Calculate the incident heat load for the site. This is obtained from reading the values shown on figure VII.7. The following is done to read values from this figure:

Step 1.6.1. — Select the correct curve (shown in fig. VII.7) obtained from the correct solar ephemeris (fig. VII.2): in this example, 35°N latitude, given a declination of +10° results in a solar angle of 65°. Note that the midday value will always have an orientation, i.e., azimuth, of due south.

Step 1.6.2. — In figure VII.7, interpolate between the 70° and 60° curves to obtain the 65° value.

Step 1.6.3. — Determine the critical period, which in step 1.4 was found to be 1 p.m. DST.

Step 1.6.4. — Find the average H value. In this example, the travel time through the reach is estimated to be 1 hour, so it is not necessary to find an average value. From figure VII.7, with a 65° midday angle, the H value for 1 p.m. is approximately 4.3 BTU/ft^2–min.

Step 1.7. — Because bedrock acts as a heat sink, reducing the heat load absorbed by the water, the H value must be corrected for this heat loss.

C is obtained from figure VII.9. In the example, bedrock comprises 75 percent of the streambed; therefore, H should be reduced by 15 percent.

$$H_{\text{adjusted}} = [\%\ WH] + [\%B\ (1.00 - C)\ H] \qquad \text{(VII.6)}$$

where for Grits Creek:

W = percent streambed without bedrock
= 25%

H = unadjusted heat load = 4.3 BTU/ft^2−min

B = percent streambed with rock = 75%

C = correction factor from figure VII.9 = 0.15

Therefore,

$$H_{\text{adjusted}} = [0.25 \times 4.3\ \text{BTU/ft}^2\text{–min}] + [0.75(1.00 - 0.15) \times 4.3\ \text{BTU/ft}^2\text{–min}]$$

$$H_{\text{adjusted}} = 3.82\ \text{BTU/ft}^2\text{–min}$$

Computing Q, Stream Discharge

Step 2. — Determine stream discharge following the proposed silvicultural activity during the critical summer low-flow period when maximum temperatures are anticipated. In this example, a pre-activity baseflow measurement during the critical summer period was taken. Discharge during the critical period was 0.5 cfs.

Computing A, Adjusted Surface Area

Step 3. — Determine the adjusted surface area of **flowing water** exposed by the proposed silvicultural activity.

Step 3.1. — Total surface area of flowing water

$$A_{\text{total}} = LW \qquad \text{(VII.7a)}$$

where:

L = length of reach exposed

W = width of flowing water

A_{total} = 2,000 ft × 5 ft
= 10,000 ft^2

Step 3.2. — Total surface area shaded by brush

$$A_{\text{shade brush}} = LW\ (\%\ \text{shaded by brush only}) \qquad \text{(VII.7b)}$$
$$= 2{,}000\ \text{ft} \times 5\ \text{ft} \times 25\%$$
$$= 2{,}500\ \text{ft}^2$$

Step 3.3. — Surface area exposed under current vegetative canopy cover: correct for transmission of light through the existing stand that has a 90-percent overstory crown closure and a 50-percent understory crown closure. Since only vertical crown closure values are available, estimate the percentage transmission of solar radiation through the canopy. In using figure VII.D.1 for crown closures greater than 70 percent, assume a 5-percent transmission of solar radiation.

$$A_{\text{presently exposed}} = (A_{\text{total}} - A_{\text{shade brush}}) \times \%\ \text{transmission through existing vegetation} \qquad \text{(VII.7c)}$$
$$= (10{,}000\ \text{ft}^2 - 2{,}500\ \text{ft}^2) \times 5\%$$
$$= 375\ \text{ft}^2$$

Step 3.4. — The adjusted surface area that will be exposed to increased solar radiation if all vegetation is removed is:

$$A_{\text{adjusted}} = A_{\text{total}} - A_{\text{presently exposed}}$$
$$= 10{,}000\ \text{ft}^2 - 375\ \text{ft}^2$$
$$= 9{,}625\ \text{ft}^2$$

Step 4. — Estimate ΔT, maximum potential daily temperature increase in °F if all vegetation is removed from lower reach. Solve equation VII.3a.

$$\Delta T = \frac{A_{\text{adjusted}} H_{\text{adjusted}}}{Q} \times 0.000267 \qquad \text{(VII.3a)}$$

A_{adjusted} = 9,625 ft^2

H_{adjusted} = 3.82 BTU/ft^2−min

Q = 0.5 cfs

= 19.6°F

$$\Delta T = \frac{(9{,}625\ \text{ft}^2)\ (3.82\ \text{BTU/ft}^2\text{–min})}{0.5\ \text{cfs}} \times 0.000267$$

The proposed silvicultural activity will only result in a partial cut of the overstory, leaving a vertical crown closure of 50 percent. The understory will not be cut; however, some loss is to be expected during removal of the overstory. Understory vertical crown closure remaining after the silvicultural activity is expected to be 45 percent. It is estimated that the percent transmission of solar radiation through the canopy will be 15 percent. The brush shading the stream will remain.

Therefore,

$$A_{\text{total}} = 2{,}000\ \text{ft} \times 5\ \text{ft} = 10{,}000\ \text{ft}^2$$

$$A_{\text{shade brush}} = 2{,}000\ \text{ft} \times 5\ \text{ft} \times 25\% = 2{,}500\ \text{ft}^2$$

$$A_{\text{shade remaining canopies}} = (10{,}000\ \text{ft}^2 - 2{,}500\ \text{ft}^2) \times 85\% = 6{,}375\ \text{ft}^2$$

$$A_{\text{adjusted}} = A_{\text{total}} - (A_{\text{presently exposed}} + A_{\text{shade brush}} + A_{\text{shade remaining canopies}})$$
$$= 10{,}000\ \text{ft}^2 - (375\ \text{ft}^2 + 2{,}500\ \text{ft}^2 + 6{,}375\ \text{ft}^2)$$
$$= 750\ \text{ft}^2$$

Step 4. — Estimate ΔT, maximum potential daily temperature increase in °F if the proposed silvicultural activity is implemented. Solve equation VII.3a.

$$\Delta T = \frac{A_{\text{adjusted}} H_{\text{adjusted}}}{Q} \times 0.000267 \qquad \text{(VII.3a)}$$

$$\begin{aligned} A_{\text{adjusted}} &= 750\ \text{ft}^2 \\ H_{\text{adjusted}} &= 3.82\ \text{BTU/ft}^2\text{–min} \\ Q &= 0.5\ \text{cfs} \end{aligned}$$

$$\Delta T = \frac{(750\ \text{ft}^2)\ (3.82\ \text{BTU/ft}^2\text{–min})}{0.5\ \text{cfs}} \times 0.000267$$

$$= 1.5°\text{F}$$

Middle Reach

Computing H, Adjusted Incident Heat Load

Step 1. — The only difference between the lower reach and the middle reach, when estimating H, is that the average width of flowing water is reduced from 5 feet to 3.5 feet. Thus, the effective stream width values would change, but the final H adjusted value would remain unchanged—3.82 BTU/ft²–min.

Computing Q, Stream Discharge

Step 2. — A pre-silvicultural activity baseflow measurement during the critical summer period was taken for this reach. Discharge during the critical period was 0.3 cfs.

Computing A, Adjusted Surface Area

Step 3. — Determine the adjusted surface area of **flowing water** exposed by the proposed silvicultural activity.

Step 3.1. — Total surface area of flowing water

$$\begin{aligned} A_{\text{total}} &= LW \qquad \text{(VII.7a)} \\ &= 1{,}800\ \text{ft} \times 3.5\ \text{ft} \\ &= 6{,}300\ \text{ft}^2 \end{aligned}$$

Step 3.2. — Total surface area shaded by brush

$$\begin{aligned} A_{\text{shade brush}} &= LW\ (\%\ \text{stream shaded by brush only}) \qquad \text{(VII.7b)} \\ &= 1{,}800\ \text{ft} \times 3.5\ \text{ft} \times 40\% \\ &= 2{,}520\ \text{ft}^2 \end{aligned}$$

Step 3.3. — Surface area exposed under current vegetative canopy cover: correct for transmission of light through the existing stand that has a 90-percent overstory crown closure and a 55-percent understory crown closure. Since only vertical crown closure values are available, estimate the percentage of solar radiation through the canopy. Again it is estimated that only 5-percent transmission of solar radiation is allowed through the canopies (fig. VII.D.1)

$$\begin{aligned} A_{\text{presently exposed}} &= (A_{\text{total}} - A_{\text{shade brush}})\ \%\ \text{transmission through existing vegetation} \qquad \text{(VII.7c)} \\ &= (6{,}300\ \text{ft}^2 - 2{,}520\ \text{ft}^2) \times 5\% \\ &= 189\ \text{ft}^2 \end{aligned}$$

Step 3.4. — The adjusted surface area that will be exposed to increased solar radiation if all vegetation is removed is:

$$\begin{aligned} A_{\text{adjusted}} &= A_{\text{total}} - A_{\text{presently exposed}} \\ &= 6{,}300\ \text{ft}^2 - 189\ \text{ft}^2 \\ &= 6{,}111\ \text{ft}^2 \end{aligned}$$

Step 4. — Estimate ΔT, maximum potential daily temperature increase in °F if all vegetation is removed from middle reach. Solve equation VII.3a

$$\Delta T = \frac{A_{\text{adjusted}} H_{\text{adjusted}}}{Q} \times 0.000267 \qquad \text{(VII.3a)}$$

$$\begin{aligned} A_{\text{adjusted}} &= 6{,}111\ \text{ft}^2 \\ H_{\text{adjusted}} &= 3.82\ \text{BTU/ft}^2\text{–min} \\ Q &= 0.3\ \text{cfs} \end{aligned}$$

$$\Delta T = \frac{(6{,}111\ \text{ft}^2)\ (3.82\ \text{BTU/ft}^2\text{–min})}{0.3\ \text{cfs}} \times 0.000267$$

$$= 29.7°\text{F}$$

The proposed silvicultural activity will only result in a partial cut of the overstory, leaving a crown closure of 50 percent. The understory will not be cut; however, some loss is expected during removal of the overstory. Understory vertical crown closure is expected to be 50 percent. It is estimated that the percent transmission of solar radiation though the canopy will be 10 percent. The brush shading the stream will remain.

Therefore,

$$\begin{aligned}
A_{\text{total}} &= 1{,}800\text{ ft} \times 3.5\text{ ft}\\
&= 6{,}300\text{ ft}^2\\
A_{\text{shade brush}} &= 1{,}800\text{ ft} \times 3.5\text{ ft} \times 40\%\\
&= 2{,}520\text{ ft}^2\\
A_{\substack{\text{shade remaining}\\ \text{canopies}}} &= (6{,}300\text{ ft} - 2{,}520\text{ ft}) \times 90\%\\
&= 3{,}402\text{ ft}^2\\
A_{\text{adjusted}} &= A_{\text{total}} - (A_{\text{presently exposed}}\\
&\quad + A_{\text{shade brush}}\\
&\quad + A_{\text{shade remaining canopies}})\\
&= 6{,}300\text{ ft}^2 - (189\text{ ft}^2\\
&\quad + 2{,}520\text{ ft}^2 + 2{,}402\text{ ft}^2)\\
&= 189\text{ ft}^2
\end{aligned}$$

Step 4. — Estimate ΔT, maximum potential daily temperature increase in °F if the proposed silvicultural activity is implemented. Solve equation VII.3a.

$$\Delta T = \frac{A_{\text{adjusted}} H_{\text{adjusted}}}{Q} \times 0.00027 \qquad \text{(VII.3a)}$$

$$\begin{aligned}
A_{\text{adjusted}} &= 189\text{ ft}^2\\
H_{\text{adjusted}} &= 3.82\text{ BTU/ft}^2\text{-min}\\
Q &= 0.3\text{ cfs}
\end{aligned}$$

$$\begin{aligned}
\Delta T &= \frac{(189\text{ ft}^2)\ (3.82\text{ BTU/ft}^2\text{-min})}{0.3\text{ cfs}} \times 0.000267\\
&= 0.6°\text{F}
\end{aligned}$$

Upper Reach

Computing H, Adjusted Incident Heat Load

Step 1. — The only difference between the lower and middle reaches and the upper reach, when estimating H, is that the average width of flowing water is reduced to 2.5 feet. Because of this, the effective stream width values would change, but the final H adjusted value would remain unchanged—3.82 BTU/ft²-min.

Computing Q, Stream Discharge

Step 2. — A pre-silvicultural activity baseflow measurement was taken for this reach during the critical summer period, resulting in a value of 0.2 cfs.

Computing A, Adjusted Surface Area

Step 3. — Determine the adjusted surface area of **flowing water** exposed by the proposed silvicultural activity.

Step 3.1. — Total surface area of flowing water

$$\begin{aligned}
A_{\text{total}} &= LW \qquad \text{(VII.7a)}\\
&= 1{,}000\text{ ft} \times 3.0\text{ ft}\\
&= 3{,}000\text{ ft}^2
\end{aligned}$$

Step 3.2. — Total surface area shaded by brush

$$\begin{aligned}
A_{\text{shade brush}} &= LW\ (\%\text{ stream shade by brush only})\\
&= 1{,}000\text{ ft} \times 3.0\text{ ft} \times 65\% \qquad \text{(VII.7b)}\\
&= 1{,}950\text{ ft}^2
\end{aligned}$$

Step 3.3. — Surface area exposed under current vegetative canopy cover; correct for transmission of light through the existing stand that has an 80-percent overstory crown closure and a 60-percent understory crown closure. Since only vertical crown closure values are available, estimate the percentage of solar radiation through the canopy. It is estimated that only 5-percent transmission of solar radiation is allowed through the canopies (fig. VII.D.1).

$$\begin{aligned}
A_{\text{presently exposed}} &= (A_{\text{total}} - A_{\text{shade brush}})\ \%\text{ transmission through existing vegetation}\\
&= (3{,}000\text{ ft}^2 - 1{,}950\text{ ft}^2) \times 5\%\\
&= 53\text{ ft}^2
\end{aligned}$$

Step 3.4. — The adjusted surface area that will be exposed to increased solar radiation if all vegetation is removed is:

$$\begin{aligned}
A_{\text{adjusted}} &= A_{\text{total}} - A_{\text{presently exposed}}\\
&= 3{,}000\text{ ft}^2 - 53\text{ ft}^2\\
&= 2{,}947\text{ ft}^2
\end{aligned}$$

Step 4. — Estimate ΔT, maximum potential daily temperature increase in °F if all vegetation is removed from the upper reach. Solve equation VII.3a.

$$\Delta T = \frac{A_{\text{adjusted}} H_{\text{adjusted}}}{Q} \times 0.000267 \qquad \text{(VII.3a)}$$

$$\begin{aligned}
A_{\text{adjusted}} &= 2{,}947\text{ ft}^2\\
H_{\text{adjusted}} &= 3.82\text{ BTU/ft}^2\text{-min}\\
Q &= 0.2\text{ cfs}
\end{aligned}$$

$$\begin{aligned}
\Delta T &= \frac{(2{,}947\text{ ft}^2)\ (3.82\text{ BTU/ft}^2\text{-min})}{0.2\text{ cfs}} \times 0.000267\\
&= 15.0°\text{F}
\end{aligned}$$

The proposed silvicultural activity will be a commercial clearcut resulting in the complete removal of the overstory and understory canopies. The dense laurel and rhododendron brush along the stream will not be removed.

Therefore,

$$
\begin{aligned}
A_{total} &= 1{,}000\text{ ft} \times 3\text{ ft} \\
&= 3{,}000\text{ ft}^2 \\
A_{shade\ brush} &= 1{,}000\text{ ft} \times 3\text{ ft} \times 65\% \\
&= 1{,}950\text{ ft}^2 \\
A_{adjusted} &= A_{total} - (A_{presently\ exposed} \\
&\quad + A_{shade\ brush}) \\
&= 3{,}000\text{ ft}^2 - (53\text{ ft}^2 + 1{,}950\text{ ft}^2) \\
&= 997\text{ ft}^2
\end{aligned}
$$

Step 4. — Estimate ΔT, maximum potential daily temperature increase in °F if the proposed silvicultural activity is implemented. Solve equation VII.3a.

$$\Delta T = \frac{A_{adjusted} H_{adjusted}}{Q} \times 0.000267 \qquad \text{(VII.3a)}$$

$$
\begin{aligned}
A_{adjusted} &= 997\text{ ft}^2 \\
H_{adjusted} &= 3.82\text{ BTU/ft}^2\text{–min} \\
Q &= 0.2\text{ cfs}
\end{aligned}
$$

$$
\begin{aligned}
\Delta T &= \frac{(997\text{ ft}^2)\ (3.82\text{ BTU/ft}^2\text{–min})}{0.2\text{ cfs}} \times 0.000267 \\
&= 5.2°\text{F}
\end{aligned}
$$

The Mixing Ratio Formula

The lower reach of Grits Creek is to be partially cut, with a potential temperature increase of 1.5°F. The middle reach will also be partially cut, with a potential temperature increase of 0.6°F. The upper reach is to be clearcut, with a potential temperature increase of 5.1°F.

An estimate of the integrated impact on the water temperature is necessary so that a comparison can be made with the water quality objective—allowing a maximum temperature increase of 3°F.

A mixing ratio formula will be used to estimate the downstream temperature impacts. The water temperature before the silvicultural activity was 63°F, and the groundwater temperature measured at a spring was 48°F.

For the upper reach, the estimated water temperature increase, 5.1°F, is added to the presilvicultural activity water temperature 63°F, to estimate the temperature of the water as it leaves the proposed clearcut area, 5.1°F + 63°F = 68.1°F.

The water temperature entering the middle reach will be 68.1°F. The estimated water temperature increase in the middle reach is 0.6°F. However, the two values should not be added to get an estimate of the water temperature leaving the middle reach because groundwater influxes within this reach will mitigate the water temperature increase caused by the proposed silvicultural activity. The following mixing ratio formula should be used:

$$T_D = \frac{D_M T_M + D_T T_T}{D_M + D_T} \qquad \text{(VII.9)}$$

where:

T_D = temperature downstream where the middle and lower reaches are separated

D_G = discharge of groundwater, 0.05 cfs

D_t = discharge immediately below partial cut, 0.30 cfs

T_G = temperature groundwater, 48°F

T_T = stream temperature below silvicultural activity which is equal to the temperature above plus computed temperature increase, 68.7°F

$$T_T = T_A + \Delta T$$

T_A = temperature streams above treated (partial cut) area, 68.1°F

ΔT = temperature increase, 0.6°F

Therefore,

$$
\begin{aligned}
T_D &= \frac{(0.05\text{ cfs})\ (48°\text{F}) + (0.25\text{ cfs})\ (68.7°\text{F})}{(0.05\text{ cfs}) + (0.25\text{ cfs})} \\
&= 65.3°\text{F}
\end{aligned}
$$

The water temperature entering the lower reach will be 65.3°F. The estimated water temperature increase in the lower reach is 1.5°F. Again, the two values should not be added as explained above. The following mixing ratio formula should be used:

$$T_D = \frac{D_G T_G + D_T T_T}{D_G + D_T} \qquad \text{(VII.9)}$$

where:

T_D = temperature downstream where lower reach ends

D_G = discharge of groundwater, 0.05 cfs

D_T = discharge immediately below partial cut, 0.50 cfs

T_G = temperature of groundwater, 48°F

T_T = stream temperature below silvicultural activity which is equal to the temperature above plus computed temperature increase, 66.8°F

$$T_T = T_A + \Delta T$$

T_A = temperature stream above treated (partial cut) area, 65.3°F

ΔT = temperature increase, 1.5°F

Therefore,

$$T_D = \frac{(0.05 \text{ cfs})\ (48°\text{F}) + (0.45 \text{ cfs})\ (66.8°\text{F})}{(0.05 \text{ cfs}) + (0.45 \text{ cfs})}$$

$$= 64.9°\text{F}$$

The estimated overall water temperature increase at the mouth would be 1.9°F (64.9°F − 63°F = 1.9°F). This value is entered in the tables VIII.2 and VIII.3 for both management alternatives.

ANALYSIS REVIEW

The estimated outputs are summarized in tables VIII.2 and VIII.3 for Grits Creek alternatives A and B, respectively. These estimates must be compared to the water quality objectives to determine if one or both of the alternatives are acceptable.

In determining acceptability of the alternatives, accuracy of the estimations must be considered. The two major sources of variation affecting accuracy of outputs are: (1) models, which by their very nature, cannot completely represent all factors affecting the estimated output, and (2) quality of input data — there is a decrease in the accuracy of the estimated output as the quality of the input data decreases. Establishing an acceptable level of accuracy for the estimated outputs is left to the professional judgment of a user who understands the strengths and weaknesses of the models and data sets used.

The computed outputs for total potential sediment from all sources and the potential temperature changes are compared to the water quality objective at the mouth of the watershed. The water quality objective for Grits Creek was to maintain channel stability, limit total potential sediment discharge to 25.5 tons/yr, and limit the maximum temperature increase to 3°F. The post-silvicultural activity total suspended sediment discharge from all sources was 26.3 tons/yr for alternative B and 53.8 tons/yr for alternative A (tables VIII.2 and VIII.3). Although alternative B resulted in 0.8 tons/yr in excess of the allowable maximum, it was judged to be within the accuracy range for the data and models used. Since both alternatives were consistent with temperature objectives, the mix of controls in alternative B was considered acceptable from a water quality standpoint.

Table VIII.2

Summary of quantitative outputs for: Alternative A, Grits Creek

Chapter	Line No.	Output description		Computed value		Chapter reference (worksheets)
				Pre-activity	Post-activity	
Hydrology: Chapter III	1	Water available for annual streamflow		104.9 cm	120.8 cm	III.1, III.2
	2	Increase in water available for annual streamflow			15.9 cm	III.1, III.2
	3	Peak discharge		13.1 cm	13.1 cm	III.3, III.4
	4	Date of peak discharge		N. A.	N. A.	
	5	Hydrograph		N. A	N. A.	
	6	7-day flow duration curve		fig VIII.3	fig. VIII.3	III.3, III.4
Surface Erosion: Chapter IV	7	Surface soil loss		N. A.	3300 tons/yr	IV.3
	8	Sediment delivered to stream channel		N. A.	34.2 tons/yr	IV.8
Soil Mass Movement: Chapter V	9	Hazard index				
	10	Weight of sediment	Coarse >0.062 mm			
	11		Fine <0.062 mm	(No soil Mass Movement)		
	12		Total			
	13	Acceleration factor				
Total Potential Sediment: Chapter VI	14	Sediment discharge due to flow change	Bedload	0.0 tons/yr	0.0 tons/yr	VI.3 line E VI.3 line F
	15		Suspended	11.6 tons/yr	19.6 tons/yr	VI.3 line A VI.3 line B
	16		Total	11.6 tons/yr	19.6 tons/yr	VI.3 line K VI.3 line G
	17	Total suspended sediment discharge from all sources		11.6 tons/yr	53.8 tons/yr	VI.3 line A line I.1 + A
	18	Increase in total potential bedload plus suspended sediment from all sources			42.2 tons/yr	VI.3 line M
Temperature: Chapter VII	19	Potential temperature changes			1.5°F	VII.2

Table VIII.3

Summary of quantitative outputs for: Alternative B, Grits Creek

Chapter	Line No.	Output description		Computed value		Chapter reference (worksheets)
				Pre-activity	Post-activity	
Hydrology: Chapter III	1	Water available for annual streamflow		104.9 cm	120.8 cm	III.1, III.2
	2	Increase in water available for annual streamflow			15.9 cm	III.1, III.2
	3	Peak discharge		13.1 cm	13.1 cm	III.3, III.4
	4	Date of peak discharge		N.A.	N.A.	
	5	Hydrograph		N.A	N.A.	
	6	7-day flow duration curve		fig VIII.3	fig VIII.3	III.3, III.4
Surface Erosion: Chapter IV	7	Surface soil loss		N.A.	240 tons/yr	IV.3
	8	Sediment delivered to stream channel		N.A.	6.7 tons/yr	IV.8
Soil Mass Movement: Chapter V	9	Hazard index				
	10	Weight of sediment	Coarse >0.062 mm			
	11		Fine <0.062 mm	(No Soil Mass Movement)		
	12		Total			
	13	Acceleration factor				
Total Potential Sediment: Chapter VI	14	Sediment discharge due to flow change	Bedload	0.0 tons/yr	0.0 tons/yr	VI.3 line E VI.3 line F
	15		Suspended	11.6 tons/yr	19.6 tons/yr	VI.3 line A VI.3 line B
	16		Total	11.6 tons/yr	19.6 tons/yr	VI.3 line K VI.3 line G
	17	Total suspended sediment discharge from all sources		11.6 tons/yr	26.3 tons/yr	VI.3 line A line I.1+ A
	18	Increase in total potential bedload plus suspended sediment from all sources			14.7 tons/yr	VI.3 line M
Temperature: Chapter VII	19	Potential temperature changes			1.5°F	VII.2

Worksheets for Grits Creek alternatives A and B

Worksheets are presented in numerical order with all III.1-III.4 alternative A, followed by III.1-III.4 alternative B; IV.1-IV.8 alternative A, followed by IV.1-IV.8 alternative B, etc.

WORKSHEET III.1

Water available for streamflow for the existing condition in rainfall dominated regions

(1) Watershed name Grits Creek (2) Hydrologic region 2 (3) Total watershed area (acres) 356 (4) Latitude 35°

Season name/ dates (5)	Silvicultural prescription		Area		Precipi- tation (cm) (10)	Baseline ET (cm) (11)	Basal area (ft^2/ac) (12)	Leaf area index (13)	ET modifier coef. (14)	Rooting depth modifier coef. (15)	Weighted adjusted ET (cm) (16)	Weighted adjusted seasonal ET (cm) (17)	Water available for sea- sonal stream- flow (cm) (18)
	Compartment (6)	Silvicultural state (7)	Acres (8)	Per- cent (9)									
Fall 9/1 - 11/31	Unimpacted	Forested	356	1.000	23.3	20.1		6	1.0	1.0	20.1		
	Impacted												
	Toral for season		356	1.000	23.3						20.1	20.1	3.2
Winter 12/1 - 2/28	Unimpacted	Forested	356	1.000	75.2	8.9		6	1.0	1.0	8.9		
	Impacted												
	Total for season		356	1.000	75.2						8.9	8.9	66.3
Spring 3/1 - 5/31	Unimpacted	Forested	356	1.000	60.5	13.0		6	1.0	1.0	13.0		
	Impacted												
	Total for season		356	1.000	60.5						13.0	13.0	47.5
Summer 6/1 - 8/31	Unimpacted	Forested	356	1.000	27.0	39.1		6	1.0	1.0	39.1		
	Impacted												
	Total for season		356	1.000	27.0						39.1	39.1	-12.1
(19) Annual ET (cm)												81.1	
(20) Water available for annual streamflow (cm)													104.9

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in text.
(3),(4)	Supplied by user.
(5)	Seasons for rainfall dominated regions are fall (September, October, November), winter (December, January, February), spring (March, April, May), and summer (June, July, August).
(6)	The unimpacted compartment includes areas not affected by the silvicultural prescription. The impacted compartment includes areas affected by the silvicultural prescription.
(7)	Areas of similar hydrologic response as identified and delineated by vegetation or silvicultural state.
(8)	Supplied by user.
(9)	Column (8) ÷ item (3).
(10)	Measured or estimated by the user.
(11)	From figures III.10 to III.12; or user supplied.
(12)	Supplied by user. Unnecessary if leaf area index is known.
(13)	From figures III.13 and III.14; or user supplied.
(14)	From figures III.15 to III.17.
(15)	From figures III.18 to III.20.
(16)	Calculated as (11) x (14) x (15) x (9); or user supplied.
(17)	Seasonal sum of column (16).
(18)	Column (10) - column (17).
(19)	Sum of column (17).
(20)	Sum of column (18).

WORKSHEET III.2

Water available for streamflow for the proposed condition in rainfall dominated regions

(1) Watershed name Grits Creek (2) Hydrologic region 2 (3) Total watershed area (acres) 356 (4) Latitude 35°

Season name/ dates (5)	Silvicultural prescription		Area		Precipi-tation (cm) (10)	Baseline ET (cm) (11)	Basal area (ft^2/ac) (12)	Leaf area index (13)	ET modifier coef. (14)	Rooting depth modifier coef. (15)	Weighted adjusted ET (cm) (16)	Weighted adjusted seasonal ET (cm) (17)	Water available for sea-sonal stream-flow (cm) (18)
	Compartment (6)	Silvicultural state (7)	Acres (8)	Per-cent (9)									
Fall 9/1 - 11/31	Unimpacted	Forested	84	.236	23.3	20.1		6	1.00	1.0	4.74		
	Impacted	Clearcut	180	.506	23.3	20.1		2	.81	1.0	8.23		
		Thinned	92	.258	23.3	20.1		3	.90	1.0	4.67		
	Total for season		356	1.000	23.3						17.64	17.6	5.7
Winter 12/1 - 2/28	Unimpacted	Forested	84	.236	75.2	8.9		6	1.00	1.0	2.10		
	Impacted	Clearcut	180	.506	75.2	8.9		2	.65	1.0	2.93		
		Thinned	92	.258	75.2	8.9		3	.76	1.0	1.75		
	Total for season		356	1.000	75.2						6.78	6.8	68.4
Spring 3/1 - 5/31	Unimpacted	Forested	84	.236	60.5	13.0		6	1.00	1.0	3.07		
	Impacted	Clearcut	180	.506	60.5	13.0		2	.60	1.0	3.95		
		Thinned	92	.258	60.5	13.0		3	.72	1.0	2.41		
	Total for season		356	1.000	60.5						9.43	9.4	51.1
Summer 6/1 - 8/31	Unimpacted	Forested	84	.236	27.0	39.1		6	1.00	1.0	9.23		
	Impacted	Clearcut	180	.506	27.0	39.1		2	.67	1.0	13.65		
		Thinned	92	.258	27.0	39.1		3	.84	1.0	8.47		
	Total for season		356	1.000	27.0						31.35	31.4	-4.4
(19) Annual ET (cm)												65.2	
(20) Water available for annual streamflow (cm)													120.8

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in text.
(3),(4)	Supplied by user.
(5)	Seasons for rainfall dominated regions are fall (September, October, November), winter (December, January, February), spring (March, April, May), and summer (June, July, August).
(6)	The unimpacted compartment includes areas not affected by the silvicultural prescription. The impacted compartment includes areas affected by the silvicultural prescription.
(7)	Areas of similar hydrologic response as identified and delineated by vegetation or silvicultural state.
(8)	Supplied by user.
(9)	Column (8) ÷ Item (3).
(10)	Measured or estimated by the user.
(11)	From figures III.10 to III.12; or user supplied.
(12)	Supplied by user. Unnecessary if leaf area index is known.
(13)	From figures III.13 and III.14; or user supplied.
(14)	From figures III.15 to III.17.
(15)	From figures III.18 to III.20.
(16)	Calculated as (11) x (14) x (15) x (9); or user supplied.
(17)	Seasonal sum of column (16).
(18)	Column (10) - column (17).
(19)	Sum of column (17).
(20)	Sum of column (18).

WORKSHEET III.3

Flow duration curve for existing condition
rain dominated regions

(1) Watershed name Grits Creek (2) Hydrologic region 2

(3) Water available for annual streamflow existing condition (cm) 104.9

(4) Annual flow from duration curve for hydrologic region (cm) 72.0

(5) Adjustment ratio (3)/(4) 1.457

Point number i (6)	Percent of time flow is equaled or exceeded (7)	Regional flow (cm/7 days) (8)	Existing potential flow Q_i (cm/7 days) (9)	Existing potential flow Q_i (cfs) (10)
1	0	9.0	13.1	11.0
2	10	2.7	3.9	3.3
3	20	1.9	2.8	2.4
4	30	1.4	2.0	1.7
5	40	1.2	1.8	1.5
6	50	.7	1.0	.8
7	60	.5	.7	.6
8	70	.4	.6	.5
9	80	.3	.4	.3
10	90	.2	.3	.25
11	100	0	0	0

Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in text.
(3)	Item (20) of worksheet III.1.
(4)	From figure III.22.
(5)	Item (3) ÷ item (4).
(6)	Number of each point taken from figure III.22; or user supplied.
(7)	X-axis of figure III.22.
(8)	From figure III.22; or user supplied (unnecessary if col. (9) is user supplied).
(9)	Column (8) x item (5); or user supplied.
(10)	Column (9) x area (acres) x 0.002363.

WORKSHEET III.4

Flow duration curve for proposed condition
rain dominated regions--annual hydrograph unavailable

(1) Watershed name Grits Creek (2) Hydrologic region 2 (3) Watershed aspect code (AS) 0

(4) Existing condition LAI 6.0 (5) Proposed condition LAI 3.2 (6) Change in LAI (CD) 2.8

(7) Rooting depth modifier coefficient (RD) 1 (8) b_0 -.03 (9) b_1 -.03 (10) b_2 .13 (11) b_3 .02 (12) b_4 .03

Point number i (13)	Percent of time flow is equaled or exceeded (14)	Existing potential flow Q_i (15)	b_0 (16)	b_1Q_i (17)	b_2CD (18)	b_3AS (19)	b_4RD (20)	ΔQ_i (cm) (21)	$Q_i + \Delta Q_i$ (cm) (22)	$Q_i + \Delta Q_i$ (cfs) (23)
1	0	13.1	-.03	-.39	.36	0	.03	-.03	13.1	11.0
2	10	3.9	-.03	-.12	.36	0	.03	.24	4.1	3.4
3	20	2.8	-.03	-.08	.36	0	.03	.28	3.1	2.6
4	30	2.0	-.03	-.06	.36	0	.03	.30	2.3	1.9
5	40	1.8	-.03	-.05	.36	0	.03	.31	2.1	1.8
6	50	1.0	-.03	-.03	.36	0	.03	.33	1.3	1.1
7	60	.7	-.03	-.02	.36	0	.03	.34	1.0	.8
8	70	.6	-.03	-.02	.36	0	.03	.34	.9	.76
9	80	.4	-.03	-.01	.36	0	.03	.35	.8	.67
10	90	.3	-.03	-.01	.36	0	.03	.35	.7	.59
11	100	0	-.03	0	.36	0	.03	.36	.4	.34

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces given in the text.
(3)	Northern aspect = +1, southern aspect = -1, eastern or western aspect = 0.
(4)	Area weighted average for existing condition.
(5)	Area weighted average for proposed condition.
(6)	Item (4) - item (5).
(7)	Area weighted average.
(8)-(12)	From tables III.3 to III.5.

Item or Col. No.	Notes
(13)	Column (6) of worksheet III.3.
(14)	Column (7) of worksheet III.3.
(15)	Column (9) of worksheet III.3.
(16)	Item (8).
(17)	Item (9) x column (15).
(18)	Item (10) x item (6).
(19)	Item (11) x item (3).
(20)	Item (12) x item (7).
(21)	Columns (16) + (17) + (18) + (19) + (20).
(22)	Column (15) + column (21).
(23)	Column (22) x area (ac) x 0.002363 for 7-day intervals.

WORKSHEET IV.1

Soil characteristics for the Grits Creek watershed

Soil group		Percent sand 2.0-0.1 mm	Percent very fine sand 0.10-0.05 mm	Percent "coarse silt" 0.062-0.05 mm[1]	Percent silt 0.05-0.002 mm	Percent clay <0.002 mm	Percent organic matter	Soil structure		Soil permeability	
								MSLE code	Descriptive	MSLE code	Inches per hour
1	Topsoil	40	17	2	18	25	4.0	2	FINE GRANULAR	3	0.6-2.0
	Subsoil	55	16	1	14	15	1.0	4	MASSIVE	3	0.6-2.0
2	Topsoil	40	18	2	22	20	4.0	2	FINE GRANULAR	2	2.0-6.0
	Subsoil	60	17	1	13	10	1.0	4	MASSIVE	2	20-6.0
3	Topsoil	30	19	3	26	25	4.0	2	FINE GRANULAR	3	0.6-2.0
	Subsoil	40	17	2	23	20	1.0	4	MASSIVE	3	0.6-20

[1] The "coarse silt" particle size group is not part of the USDA classification system, but 0.062 mm represents an upper limit of particle size that is used when estimating suspended sediment transport in streams. For this use only the "coarse silt" size within the USDA very fine sand classification is presented.

WORKSHEET IV.2

Grits Creek watershed erosion response unit management data for use in the MSLE and sediment delivery index, hydrographic area 13, alternative A.

Erosion response unit	Slope length of disturbed area (ft)	Slope gradient of disturbed area (%)	Length of road section [1] (ft)	Average width of disturbance (ft)	Area (sq.ft.)	Area [2] (acres)
1. SC 13.1	176	8				6.1
2. SC 13.2	286	16				5.7
3. CC 13.1	132	12				1.4
4. CC 13.2	484	20				6.4
5. R 13.1			543	16.9		0.21
6. CUT	3.5	170		1.8		
7. BED	12.0	1		12.0		
8. FILL	4.5	100		3.1		
9. R 13.2 [3]			24	18.0		0.01
10. FILL	2.0	100		1.4		
11. BED	13.0	0		13.0		
12. FILL	5.0	100		3.6		
13. R 13.5			616	23.0		0.33
14. CUT	8.0	180		3.9		
15. BED	12.0	1		12.0		
16. FILL	10.0	100		7.1		
17.						
18.						
19.						
20.						
21.						
22.						
23.						
24.						
25.						

[1] *Approximately 200 feet between water diversion dips.*

[2] *1 acre = 43,560 ft²*

[3] *This road crosses a stream. It is separated from the rest of the road because sediment is delivered directly into a channel.*

WORKSHEET IV.2--continued

	Area with surface residues			Open area				
	Percent of total area	Percent of surface with mulch	Percent of area with fine roots 4/	Percent of total area	Percent of surface with mulch	Percent of area with fine roots	Are open areas separated by filter strips?	Percent of total area with canopy
1.	40	85	99	60	55	85	YES	45
2.	45	85	99	55	50	80	YES	45
3.	55	60	99	45	45	80	YES	0
4.	60	60	99	40	45	85	YES	0
5.								
6.	0	0	0	100	0	0	NO	25
7.	0	0	0	100	0	0	NO	0
8.	60	85	50	40	0	0	NO	25
9.								
10.	60	85	50	40	0	0	NO	25
11.	0	0	0	100	0	0	NO	0
12.	60	86	50	40	0	0	NO	25
13.								
14.	0	0	0	100	0	0	NO	0
15.	0	0	0	100	0	0	NO	0
16.	60	86	50	40	0	0	NO	0
17.								
18.								
19.								
20.								
21.								
22.								
23.								
24.								
25.								

[4] *Not applicable to scalped areas until vegetation is reestablished.*

3 of 3

WORKSHEET IV.2--continued

	Average minimum height of canopy (m)	Time for recovery (mo)	Average dist. from disturbance to stream channel (ft)	Overall slope shape between disturbance and channel	Percent ground cover in filter strip	Surface roughness (qualitative)	Texture of eroded material 5/ (% silt + clay)	Percent slope between disturbance and channel
1.	2	↑	0	CONCAVE	88	MODERATE	47	8
2.	2		0	CONCAVE	86	MODERATE	57	16
3.	–		0	CONCAVE	94	MODERATE	57	12
4.	–		0	CONCAVE	90	MODERATE	50	20
5.			138	CONCAVE	88	MODERATE	38	8
6.	2							
7.	–							
8.	2							
9.			0	STRAIGHT	0	SMOOTH	38	100
10.	2							
11.	–	UNKNOWN						
12.	2							
13.			193	CONCAVE	86	MODERATE	50	16
14.	2							
15.	–							
16.	2							
17.			0	STRAIGHT	0	SMOOTH	50	100
18.	2							
19.	–							
20.	2							
21.			193	CONCAVE	94	MODERATE	50	12
22.	–							
23.	–							
24.	–	↓						
25.								

5/ *It has been assumed that ½ of the clay remains on-site as stable aggregates and that the rest of the clay plus very fine sand and silt enter the sediment delivery system.*

WORKSHEET IV.3

Estimates of soil loss and delivered sediment by erosion response unit
for hydrographic area 13 of Grits Creek watershed

Erosion response unit[1]	Soil unit[3]	R	K	LS	VM	Area (acres)	Surface soil loss (tons/yr)	SD$_1$	Delivered sediment (tons/yr)
SC13.1	T1	300	0.09	1.31	0.012	6.1	2.6	0.02	0.05
SC13.2	T3	300	0.18	4.33	0.014	5.7	18.7	0.02	0.37
CC13.1	T3	300	0.18	2.05	0.023	1.4	3.6	0.02	0.07
CC13.2	T2	300	0.14	5.92	0.023	6.4	36.6	0.0	0.0
R13.1	S1	300	0.24	6.84	0.870	0.21	90.0	0.01	0.90
R13.2	S1	300	0.24	1.81[3]	0.822	0.01	1.1	0.14	0.2
R13.5	S3	300	0.29	13.47	0.818	0.33	316	0.01	3.2

[1] *SC - Selection cut*
CC - Clearcut
R - Road

[2] *T - Topsoil*
S - Subsoil

[3] *Average of two LS values, one for each half of the road, starting at the center line and including a fill slope.*

WORKSHEET IV.4

Estimated VM factors for silvicultural erosion response units
Grits Creek watershed, hydrographic area 13.

	Logging residue area					Open area						
Erosion response unit	Fraction of total area	Mulch (duff & residue)	Canopy[1]	Roots	Sub VM	Fraction percent of total area	Mulch (duff & residue)	Canopy[1]	Roots	Filter strip	Sub VM	Total VM[3]
SC13.1	0.40	0.10	0.98 [2]	0.10	.0039	0.60	0.28	0.90	0.11	0.5	.0083	0.012
SC13.2	0.45	0.10	0.98	0.10	.0044	0.55	0.32	0.88	0.12	0.5	.0093	0.014
CC13.1	0.55	0.25	1.0	0.10	.0138	0.45	0.35	1.0	0.12	0.5	.0095	0.023
CC13.2	0.60	0.25	1.0	0.10	.015	0.40	0.35	1.0	0.11	0.5	.0077	0.023
R13.1 CUT[4]	0.0	–	–	–	0.0	1.00	1.0	0.88	-	1.0	0.880	0.88
BED	0.0	–	–	–	0.0	1.00	1.0	1.00	-	1.0	1.0	1.0
FILL	0.60	0.10	0.88	0.21	0.011	0.40	1.0	0.88	-	1.0	0.352	0.36
R13.2 FILL	0.60	0.10	0.88	0.21	0.011	0.40	1.0	0.88	-	1.0	0.352	0.36
BED	0.0	–	–	–	0.0	1.00	1.0	1.00	-	1.0	1.0	1.0
FILL	0.60	0.10	0.88	0.21	0.011	0.40	1.0	0.88	-	1.0	0.352	0.36
R13.5 CUT	0.0	–	–	–	0.0	1.00	1.0	1.0	-	1.0	1.0	1.0
BED	0.0	-	–	–	0.0	1.00	1.0	1.0	-	1.0	1.0	1.0
FILL	0.60	0.10	1.0	0.21	0.013	0.40	1.0	1.0	-	1.0	0.4	0.41

[1] *Canopy effects only apply to open areas without residue and duff.*

[2] *Example calculation: From worksheet IV.2, 85% of the surface has mulch, leaving 15% without mulch. If the canopy is uniformly distributed over 45% of the total area, then only 15% of the canopy can cover the area without mulch. Therefore: (0.15)(0.45)(100) = 7% of the area without mulch, that is covered by the canopy. This results in a VM = 0.98.*

[3] *Enter on worksheet IV.3.*

[4] *VM for roads is for a recovered condition.*

WORKSHEET IV.6

Weighting of VM values for roads in
Grits Creek watershed, hydrographic area 13.

Erosion response unit	Cut or fill		Roadbed		Fill		Weighted
	Fraction of total width	VM	Fraction of total width	VM	Fraction of total width	VM	VM
R13.1	(0.1065)	(0.88)	+ (0.7101)	(1.0)	+ (0.1834)	(0.36)	= 0.870
R13.2	(0.0778)	(0.36)	+ (0.7222)	(1.0)	+ (0.2000)	(0.36)	= 0.822
R13.5	(0.1696)	(1.0)	+ (0.5217)	(1.0)	+ (0.3087)	(0.41)	= 0.818

WORKSHEET IV.7

Factors for sediment delivery index from erosion response units in

Grits Creek watershed, hydrographic area 13.

Erosion response unit	Water availability[1]	Texture of eroded material	Percent ground cover between disturbance and channel	Slope shape code	Distance (edge of disturbance to channel) (ft)	Surface roughness code	Slope gradient (%)	Specific site factor	Percent of total area for polygon	SDI [5]
SC13.1	0.002 [2]	47	67	2.5	1	2	8	—	12.3	0.02
SC13.2	0.003 [3]	57	66	2.5	1	2	16	—	13.1	0.02
CC13.1	0.0015 [3]	57	53	2.5	1	2	12	—	13.2	0.02
CC13.2	0.0 [3]	50	67	2.5	1	2	20	—	—	0.0 [6]
R13.1	0.012 [4]	38	67	2.5	138	2	8	—	7.0	0.01
R13.2	0.001 [4]	38	0	2.0	24	1	100	—	30.9	0.14
R13.5	0.016 [4]	50	53	2.5	193	2	12	—	8.2	0.01

[1] *Maximum 15 min. annual storm of 2.5 in/hr.*

[2] *Infiltration rate of 2.0 in/hr (based on soil permeability).*

[3] *Infiltration rate of 3.0 in/hr (based on soil permeability).*

[4] *Infiltration rate of 0.1 in/hr (based on soil permeability).*

[5] *Enter on worksheet IV.3.*

[6] *When water availability is zero, then the sediment delivery index is zero.*

WORKSHEET IV.8

Estimated tons of sediment delivered to a channel for each hydrographic area and type of disturbance for Grits Creek watershed, Alternative A.

Hydrographic area	Cutting units					Roads								Total tons/yr	Percent
	SC_1	SC_2	CC_1	CC_2	CC_3	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8		
1			0.06	0.05		1.1	0.8	0.2	0.6					2.61	7.7
2			0.05	0.05		0.3	0.2	0.8						1.40	4.1
3			0.06	0.06		0.6								0.72	2.1
4			0.06	0.05		1.2								1.31	3.8
5			0.08			2.5	0.2	0.2	0.2	2.2				5.38	15.8
6			0.04			0.3	0.8	0.2	0.8	0.2				2.34	6.4
7			0.05	0.04		1.2	0.2							1.49	4.4
8			0.04			0.3	0.2							0.54	1.6
9	0.04	0.04	0.04	0.04		0.3			0.2	0.3				0.96	2.8
10	0.04		0.04			0.3	0.2	1.0	0.2					1.78	5.2
11	0.04	0.04	0.05	0.05		0.3	0.2	0.3	0.2	0.3	0.2			1.68	4.9
12	0.0		0.0			0.2	0.5	0.5	0.5					1.70	5.0
13	0.05	0.37	0.07	0.0		0.9	0.2			3.2				4.79	14.1
14	0.0	0.0	0.0			0.9	0.2			0.9				2.0	5.9
15	0.03	0.0	0.04	0.0		0.8	0.2			0.9	0.1			2.07	6.1
16	0.02	0.0	0.0			0.6	0.2			0.8				1.62	4.8
17			0.05	0.0		0.6	0.2			0.8				1.65	4.8
Column total	0.73	0.34	0.22	0.45		12.4	4.3	3.2	2.7	9.6	0.3			34.24	
Disturbance total	1.07		0.67			32.5									
Percent	3.1		2.0			94.9									

1 of 3

WORKSHEET IV.2

Grits Creek watershed erosion response unit management data for use in the MSLE and sediment delivery index, hydrographic area 13, alternative B.

Erosion response unit	Slope length of disturbed area (ft)	Slope gradient of disturbed area (%)	Length of road section (ft)	Average width of disturbance (ft)	Area (sq.ft.)	Area (acres)
1. SC 13.1	176	8				6.1
2. SC 13.2	286	16				5.7
3. CC 13.1	132	12				1.4
4. CC 13.2	484	20				6.4
5. R 13.1			543	16.9		0.21
6. CUT	3.5	170		1.8		
7. BED	12.0	1.0		12.0		
8. FILL	4.5	100		3.1		
9. R 13.2 3/			24	18.0		0.01
10. FILL	2.0	100		1.4		
11. BED	13.0	0		13.0		
12. FILL	5.0	100		3.6		
13. R13.3			543	16.6		0.21
14. CUT	4.0	170		2.0		
15. BED	11.0	2		11.0		
16. FILL	5.0	100		3.6		
17. R13.4 3/			26	18.0		0.01
18. FILL	2.5	100		1.8		
19. BED	12.0	0		12.0		
20. FILL	6.0	100		4.2		
21. R13.5			616	23.0		0.33
22. CUT	8.0	180		3.9		
23. BED	12.0	1		12.0		
24. FILL	10.0	100		7.1		
25.						

1/ *Approximately 200 feet between water diversion dips.*

2/ *1 acre = 43,560 ft*^{2}

3/ *This road section crosses a stream. It is separated from the rest of the road because sediment is delivered directly into a channel.*

WORKSHEET IV.2--continued

	Area with surface residues			Open area				
	Percent of total area	Percent of surface with mulch 4/	Percent of area with fine roots	Percent of total area	Percent of surface with mulch	Percent of area with fine roots 4/	Are open areas separated by filter strips?	Percent of total area with canopy
1.	40	100	99	60	80	99	YES	45
2.	45	100	99	55	75	99	YES	45
3.	60	100	99	40	85	99	YES	0
4.	65	95	99	35	80	99	YES	0
5.								
6.	0	0	0	100	0	0	NO	25
7.	60	85	60	40	0	60	NO	0
8.	100	85	100	0		100		25
9.								
10.	100	85	100	0		100		25
11.	60	85	60	40	0	60	NO	0
12.	100	85	100	0		100		25
13.								
14.	0	0	0	100	0	0	NO	25
15.	60	85	60	40	0	60	NO	0
16.	100	85	100	0		100		25
17.								
18.	100	85	100	0		100		25
19.	60	85	60	40	0	60	NO	0
20.	100	85	100	0		100		25
21.								
22.	0	0	0	100	0	0	NO	0
23.	60	85	60	40	0	60	NO	0
24.	100	85	100	0		100		0
25.								

4/ *Not applicable to scalped areas until vegetation is reestablished.*

WORKSHEET IV.2--continued

	Average minimum height of canopy (m)	Time for recovery (mo)	Average dist. from disturbance to stream channel (ft)	Overall slope shape between disturbance and channel	Percent ground cover in filter strip	Surface roughness (qualitative)	Texture of eroded material 5/ (% silt + clay)	Percent slope between disturbance and channel
1.	2		0	CONCAVE	67	MODERATE	47	8
2.	2		0	CONCAVE	66	MODERATE	57	16
3.			0	CONCAVE	53	MODERATE	57	12
4.			0	CONCAVE	54	MODERATE	50	20
5.			138	CONCAVE	67	MODERATE	38	8
6.	2							
7.								
8.	2	UNKNOWN						
9.			0	STRAIGHT	0	SMOOTH	38	100
10.	2							
11.								
12.	2							
13.			193	CONCAVE	53	MODERATE	50	12
14.								
15.								
16.								
17.								
18.								
19.								
20.								
21.								
22.								
23.								
24.								
25.								

5/ *It has been assumed that ½ of the clay remains on-site as stable aggregates and that the rest of the clay plus very fine sand and silt enter the sediment delivery system.*

WORKSHEET IV.3

Estimates of soil loss and delivered sediment by erosion response unit
for hydrographic area 13 of Grits Creek watershed

Erosion response unit[1]	Soil unit[2]	R	K	LS	VM	Area (acres)	Surface soil loss (tons/yr)	SD$_1$	Delivered sediment (tons/yr)
SC 13.1	T1	300	0.09	1.31	0.004	6.1	0.86	0.02	0.02
SC 13.2	T3	300	0.18	4.33	0.005	5.7	6.7	0.02	0.13
CC 13.1	T3	300	0.18	2.05	0.003	1.4	0.46	0.02	0.01
CC 13.2	T2	300	0.14	5.92	0.005	6.4	8.0	0.0	0
R 13.1	S1	300	0.24	6.84	0.153	0.21	15.8	0.01	0.16
R 13.2	S1	300	0.24	1.81[3]	0.063	0.01	0.08	0.14	0.01
R 13.3	S3	300	0.29	7.74	0.162	0.21	23.0	0.01	0.23
R 13.4	S3	300	0.29	6.03[3]	0.059	0.01	0.31	0.16	0.05
R 13.5	S3	300	0.29	13.47	0.194	0.33	75.0	0.01	0.75

[1] SC - *Selection Cut*
CC - *Clearcut*
R - *Road*

[2] T - *Topsoil*
S - *Subsoil*

[3] *Average of two LS values, one for each half of the road, starting at the center line and including a fill slope.*

WORKSHEET IV.4

Estimated VM factors for silvicultural erosion response units
Grits Creek watershed, hydrographic area 13

	Logging residue area					Open area						
Erosion response unit	Fraction of total area	Mulch (duff & residue)	Canopy	Roots	Sub VM	Fraction percent of total area	Mulch (duff & residue)	Canopy[1]	Roots	Filter strip	Sub VM	Total VM[3]
SC13.1	0.40	0.02	1.0	0.1	.0008	0.60	0.12	0.95[2]	0.1	0.5	.0034	.0042
SC13.2	0.45	0.02	1.0	0.1	.0009	0.55	0.15	0.94	0.1	0.5	.0039	.0048
CC13.1	0.60	0.02	1.0	0.1	.0012	0.40	0.09	1.0	0.1	0.5	.0018	.0030
CC13.2	0.65	0.05	1.0	0.1	.0033	0.35	0.12	1.0	0.1	0.5	.0021	.0054
R13.1[4] CUT	0.0	—	—	—	0.0	1.00	1.0	0.87	—	1.0	.0870	.870
BED	0.60	0.1	1.00	0.18	0.011	0.40	1.0	0.18	—	1.0	.072	.083
FILL	1.00	0.1	0.98	0.10	0.010	0.0	—	—	—	—	0.0	.010
R13.2 FILL	1.00	0.1	0.98	0.10	0.010	0.0	—	—	—	—	0.0	.010
BED	0.60	0.1	1.00	0.18	0.011	0.40	1.0	1.0	0.18	1.0	.072	.089
FILL	1.00	0.1	0.98	0.10	0.010	0.0	—	—	—	—	0.0	.010
R13.3 CUT	0.0	—	—	—	0.0	1.00	1.0	0.87	—	1.0	0.870	.870
BED	0.60	0.1	1.00	0.18	0.011	0.40	1.0	0.18	—	1.0	0.072	.083
FILL	1.00	0.1	0.98	0.10	0.010	0.0	—	—	—	—	0.0	.010
R13.4 FILL	1.00	0.1	0.98	0.10	0.010	0.0	—	—	—	—	0.0	.010
BED	0.60	0.1	1.00	0.18	0.011	0.40	1.0	1.0	0.18	1.0	0.072	.083
FILL	1.00	0.1	0.98	0.10	0.010	0.0	—	—	—	—	0.0	.010
R13.5 FILL	0.0	—	—	—	0.0	1.00	1.0	0.87	—	1.0	0.870	.870
BED	0.60	0.1	1.00	0.18	0.011	0.40	1.0	0.18	—	1.0	0.072	.083
FILL	1.00	0.1	0.98	0.10	0.010	0.0	—	—	—	—	0.0	.010

1/ *Canopy effects only apply to open areas without residue and duff.*

2/ *Example calculation: From worksheet IV.2, 80% of the surface in the open area has mulch, leaving 20% without mulch. If the canopy is uniformly distributed over 45% of the total area, then only 20% of the canopy can cover the area without mulch. Therefore: (0.20)(0.45)(100) = 9% of the area without mulch, that is covered by the canopy. This results in a VM = 0.95.*

3/ *Enter on worksheet IV.3.*

4/ *VM for roads is for a recovered condition.*

WORKSHEET IV.6

Weighting of VM values for roads in
Grits Creek watershed, hydrographic area 13.

Erosion response unit	Cut or fill		Roadbed		Fill		Weighted
	Fraction of total width	VM	Fraction of total width	VM	Fraction of total width	VM	VM
R 13.1	(0.1065)	(0.870)	+(0.7101)	(0.083)	+(0.1834)	(0.010)	= 0.153
R 13.2	(0.0778)	(0.010)	+(0.7222)	(0.083)	+(0.2000)	(0.010)	= 0.063
R 13.3	(0.1205)	(0.870)	+(0.6627)	(0.083)	+(0.2169)	(0.010)	= 0.162
R 13.4	(0.1000)	(0.010)	+(0.6667)	(0.083)	+(0.2333)	(0.010)	= 0.059
R 13.5	(0.1696)	(0.870)	+(0.5217)	(0.083)	+(0.3087)	(0.010)	= 0.194

WORKSHEET IV.7

Factors for sediment delivery index from erosion response units in

Grits Creek watershed, hydrographic area 13

Erosion response unit	Water availability[1]	Texture of eroded material	Percent ground cover between disturbance and channel	Slope shape code	Distance (edge of disturbance to channel) (ft)	Surface roughness code	Slope gradient (%)	Specific site factor	Percent of total area for polygon	SDI[5]
SC13.1	0.002[2]	47	88	2.5	1	2	8	—	11.9	0.02
SC13.2	0.0033[2]	57	86	2.5	1	2	16	—	12.7	0.02
CC13.1	0.0015[3]	57	94	2.5	1	2	12	—	12.1	0.02
CC13.2	0.0[3]	50	90	2.5	1	2	20	—	—	0.0[6]
R13.1	0.012[4]	38	88	2.5	500	2	8	—	5.1	0.01
R13.2	0.001[4]	38	0	2.0	24	1	100	—	30.9	0.14
R13.3	0.016[4]	50	86	2.5	700	2	16	—	6.1	0.01
R13.4	0.001[4]	50	0	2.0	26	1	100	—	22.3	0.16
R13.5	0.016[4]	50	94	2.5	700	2	12	—	5.6	0.01

1/ *Maximum 15 min. annual storm of 2.5 in/hr.*
2/ *Infiltration rate of 2.0 in/hr (based on soil permeability).*
3/ *Infiltration rate of 3.0 in/hr (based on soil permeability).*
4/ *Infiltration rate of 0.1 in/hr (based on soil permeability).*
5/ *Enter on worksheet IV.3.*
6/ *When water availability is zero, then the sediment delivery index is zero.*

WORKSHEET IV.8

Estimated tons of sediment delivered to a channel for each hydrographic area and type of disturbance for Grits Creek watershed, alternative B

Hydrographic area	Cutting units					Roads								Total tons/yr	Percent
	SC_1	SC_2	CC_1	CC_2	CC_3	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8		
1			0.01	0.01		0.2	0.1	0.01	0.1					0.43	6.4
2			0.01	0.01		0.03	0.01	0.1						0.16	2.4
3			0.01	0.01		0.1								0.12	1.8
4			0.01	0.01		0.2								0.22	3.3
5			0.02			0.6	0.01	0.01	0.01	0.5	0.2			1.35	20.1
6			0.01			0.03	0.1	0.01	0.1	0.01	0.1	0.01		0.37	5.5
7			0.01	0.01		0.2	0.01	0.1						0.33	4.9
8			0.01			0.03	0.01							0.05	0.7
9	0.01	0.01	0.01	0.01		0.03	0.01	0.1	0.01	0.03				0.22	3.3
10	0.01		0.01			0.03	0.01	0.2	0.01	0.1				0.37	5.5
11	0.01	0.01	0.01	0.01		0.03	0.01	0.03	0.01	0.03	0.01	0.03	0.01	0.20	3.0
12	0.0		0.0			0.01	0.1	0.1	0.1					0.31	4.6
13	0.02	0.13	0.01	0.0		0.2	0.01	0.2	0.05	0.7				1.32	19.7
14	0.0	0.0	0.0			0.1	0.01	0.1		0.1				0.31	4.6
15	0.01	0.0	0.01	0.0		0.1	0.01	0.1	0.05	0.1	0.02			0.40	6.0
16	0.01	0.0	0.0		0.0	0.1	0.01	0.1	–	0.1				0.32	4.8
17			0.01	0.0		0.1	0.01	–	–	0.1				0.22	3.3
Column total	0.07	0.15	0.15	0.07	0.0	2.09	0.42	1.16	0.44	1.77	0.33	0.04	0.01	6.70	
Disturbance total	0.22		0.22			6.26									
Percent	3.3		3.3			93.4									

WORKSHEET VI.1

Suspended sediment quantification for Grits Creek
(Pre and Post for Alternatives A and B)

(1) Time increment (a) With hydrographs use date; with flow duration curves use % of 365 days	(b) Number of days pre-silvicultural activity	(c) Number of days post-silvicultural activity	(2) Pre-silvicultural activity flow (cfs)	(3) Suspended sediment concentration (mg/l)	(4) Total increment suspended sediment cols. (2) x (3) x (1.b) x .0027 (tons)	(5) Post-silvicultural activity flow (cfs)	(6) Suspended sediment concentration (mg/l)	(7) Total increment post-silvicultural activity suspended sediment cols. (5) x (6) x (1.c) x .0027 (tons)	(8) Maximum concentrations from selected water quality objective (mg/l)	(9) Maximum sediment discharge cols. (2) x (8) x (1.b) x .0027 (tons)
1	3.6	3.6	8.8	32.0	0.30	8.9	34.0	0.33	75.0	0.74
5	18.2	18.2	5.5	18.0	0.89	5.9	22.0	1.08	46.0	2.26
10	36.5	36.5	3.3	12.0	1.18	3.5	14.0	1.38	26.0	2.56
20	73.0	73.0	2.3	8.0	1.58	2.5	9.0	1.78	17.0	3.35
30	109.5	109.5	1.7	6.0	1.77	1.9	7.0	2.07	13.0	3.84
40	146.0	146.0	1.2	4.0	1.58	1.7	6.0	2.36	8.1	3.15
50	182.5	182.5	0.8	3.0	1.18	1.1	4.0	1.97	6.0	2.96
60	219.0	219.0	0.5	2.0	1.18	0.8	3.0	1.77	3.6	2.13
70	255.0	255.0	0.4	1.5	1.03	0.7	2.8	1.93	2.6	1.79
80	292.0	292.0	0.3	1.2	0.95	0.6	2.5	1.97	2.0	1.58
90	328.0	328.0	0.2	NEGLI	NEGLI	0.5	2.0	1.77	1.3	1.15
100	365.0	365.0	0	NEGLI	NEGLI	0.3	1.2	1.18	—	—

(Totals are rounded to nearest tenth)

Total 11.6 tons/yr

Total 19.6 tons/yr

Total 25.5 tons/yr

Summary: Total pre-silvicultural activity suspended sediment discharge = 11.6
Total post-silvicultural activity suspended sediment discharge = 19.6
Total maximum sediment discharge = 25.5

WORKSHEET VI.3

Sediment prediction worksheet summary

Subdrainage name Grits Creek (Alternative A) Date of analysis 6/2/78

Suspended Sediment Discharge

A.	Pre-silvicultural activity total potential suspended sediment discharge (total col. (4), wksht. VI.1) (tons/yr)		11.6
B.	Post-silvicultural activity total potential suspended sediment discharge (total col. (7), wksht. VI.1) (due to streamflow increases) (tons/yr)		19.6
C.	Maximum allowable potential suspended sediment discharge (total col. (9), wksht. VI.1) (tons/yr)		25.5
D.	Potential introduced sediment sources: (delivered)		
	1. Surface erosion (tons/yr)	34.2	
	2. Soil mass movement (coarse) (tons/yr)	0	
	3. Median particle size (mm)	–	
	4. Soil mass movement--washload (silts and clays) (tons/yr)	0	

Bedload Discharge (Due to increased streamflow)

E.	Pre-silvicultural activity potential bedload discharge (tons/yr)	0
F.	Post-silvicultural activity potential bedload discharge (due to increased streamflow) (tons/yr)	0

Total Sediment and Stream Channel Changes

G.	Sum of post-silvicultural activity suspended sediment + bedload discharge (other than introduced sources) (tons/yr)	19.6 (sum B + F)
H.	Sum of total introduced sediment (D) = (D.1 + D.2 + D.4) (tons/yr)	34.2
I.	Total increases in potential suspended sediment discharge	
	1. (B + D.1 + D.4) - (A) (tons/yr)	42.2
	2. Comparison to selected suspended sediment limits (I.1) - (C) (tons/yr)	± 16.7

WORKSHEET VI.3--continued

J. Changes in sediment transport and/or channel change potential (from introduced sources and direct channel impacts)

1. Total post-silvicultural activity soil mass movement sources (coarse size only) (tons/yr) 0

2. Total post-silvicultural soil mass movement sources (fine or washload only) (tons/yr) 0

3. Particle size (median size of coarse portion) (mm) —

4. Post-silvicultural activity bedload transport (F) (tons/yr) 0

Potential for change (check appropriate blank below)

Stream deposition ____

Stream scour ____

No change ✓

K. Total pre-silvicultural activity potential sediment discharge (bedload + suspended load) (tons/yr) 11.6 (sum A + E)

L. Total post-silvicultural activity potential sediment discharge (all sources + bedload and suspended load) (tons/yr) 53.8 (sum G + H)

M. Potential increase in total sediment discharge due to proposed activity (tons/yr) 42.2 (subtract L - K)

WORKSHEET VI.3

Sediment prediction worksheet summary

Subdrainage name Grits Creek (Alternative B) Date of analysis 6/9/78

Suspended Sediment Discharge

A. Pre-silvicultural activity total potential suspended sediment discharge (total col. (4), wksht. VI.1) (tons/yr) 11.6

B. Post-silvicultural activity total potential suspended sediment discharge (total col. (7), wksht. VI.1) (due to streamflow increases) (tons/yr) 19.6

C. Maximum allowable potential suspended sediment discharge (total col. (9), wksht. VI.1) (tons/yr) 25.5

D. Potential introduced sediment sources: (delivered)

1. Surface erosion (tons/yr) 6.7
2. Soil mass movement (coarse) (tons/yr) 0
3. Median particle size (mm) –
4. Soil mass movement-- washload (silts and clays) (tons/yr) 0

Bedload Discharge (Due to increased streamflow)

E. Pre-silvicultural activity potential bedload discharge (tons/yr) 0

F. Post-silvicultural activity potential bedload discharge (due to increased streamflow) (tons/yr) 0

Total Sediment and Stream Channel Changes

G. Sum of post-silvicultural activity suspended sediment + bedload discharge (other than introduced sources) (tons/yr) 19.6 (sum B + F)

H. Sum of total introduced sediment (D) = (D.1 + D.2 + D.4) (tons/yr) 6.7

I. Total increases in potential suspended sediment discharge

1. (B + D.1 + D.4) - (A) (tons/yr) 14.7
2. Comparison to selected suspended sediment limits (I.1) - (C) (tons/yr) ± 10.8

WORKSHEET VI.3--continued

J. Changes in sediment transport and/or channel change potential (from introduced sources and direct channel impacts)

1. Total post-silvicultural activity soil mass movement sources (coarse size only) (tons/yr) 0

2. Total post-silvicultural soil mass movement sources (fine or washload only) (tons/yr) 0

3. Particle size (median size of coarse portion) (mm) —

4. Post-silvicultural activity bedload transport (F) (tons/yr) 0

Potential for change (check appropriate blank below)

Stream deposition ___

Stream scour ___

No change [✓]

K. Total pre-silvicultural activity potential sediment discharge (bedload + suspended load) (tons/yr) 11.6 (sum A + E)

L. Total post-silvicultural activity potential sediment discharge (all sources + bedload and suspended load) (tons/yr) 26.3 (sum G + H)

M. Potential increase in total sediment discharge due to proposed activity (tons/yr) 14.7 (subtract L - K)

WORKSHEET VII.1

Variation of solar azimuth and angle with time of day

Time of day (Daylight savings time)	Solar azimuth (degrees)	Stream[1] effective width (EW) (ft)	Solar angle (degrees)	Shadow[2] length (S) (ft)
12:30	155	1.6	70	25.4
1:00 Solar noon	180	2.1	72	22.7
1:30	205	4.4	70	25.5
2:10 Oriented Width Stream	225	Infinity	68	28.2
2:30	235	8.6	65	32.6
2:45	240	5.8	60	40.4
3:10	245	4.4	55	49.0

[1] $EW = \dfrac{\text{measured average stream width}}{\text{sine} \mid \text{azimuth stream} - \text{azimuth sun} \mid}$

[2] $S = \dfrac{\text{height vegetation}}{\text{tangent solar angle}}$

WORKSHEET VII.2

Evaluation of downstream temperature impacts

Stream reach	$A_{adjusted}$ ft²	$H_{adjusted}$ BTU/ft²-min	Q		ΔT 1/ °F	T 2/ °F
			Surface cfs	Subsurface cfs		
UPPER	997	3.82	0.2		5.2	68.1
MIDDLE	189	3.82	0.25	0.05	0.6	65.3
LOWER	750	3.82	0.45	0.05	1.5	64.9

1/ $\Delta T = \frac{A_{adjusted} \times H_{adjusted}}{Q} \times 0.000267$ where Q is surface flow only.

2/ T from mixing ratio equation.

PROCEDURAL EXAMPLE FOR HORSE CREEK—A SNOW DOMINATED HYDROLOGIC REGION

DESCRIPTION OF AREA AND PROPOSED SILVICULTURAL ACTIVITY

The Timber Management Assistant on the Glacier Ranger District, Rocky National Forest[3], prepared a 5-year timber management plan for the district. After cruising the Horse Creek drainage, he determined that a sale of 600,000 board feet of lodgepole pine was warranted based upon the stand condition and timber market.

The sale has been designed as a group of 24 small clearcut blocks of approximately 12.5 acres each. The blocks have been designated in the field with orange marking paint. Engineering has flagged the center lines of the roads that will need to be constructed and has surveyed the actual location, collecting sufficient data to design the roads to forest standards. See figures IV.17 and IV.18 for the road locations and layout of proposed clearcut blocks.

Resource specialists have been asked to review the proposed sale and to evaluate potential impacts. Information from a general soil survey of the area is available.

Water Quality Objectives

The established water quality objectives required that suspended sediment discharge be limited to 38.6 tons/yr and that water temperature increases be no greater than 1.5°F for the Horse Creek drainage.

DATA BASE

Necessary data have been obtained from resource specialists in timber, soils, hydrology, and engineering.

The collected data are presented in table VIII.4. A complete water resource evaluation includes analyses in the following categories (numbers for the corresponding chapters in this handbook appear in parentheses):

Hydrology (III)
Surface Erosion (IV)
Soil Mass Movement (V)
Total Potential Sediment (VI)
Temperature (VII)

HYDROLOGY ANALYSIS

Horse Creek is situated in hydrologic region 4, a snow dominated region. The procedure presented in "Chapter III: Hydrology" for the snow dominated regions (including wkshts. III.5, III.6, III.7, and III.8, proposed and revised worksheets are located at the end of section "Procedural Example For Horse Creek—. . .") is applied to estimate potential volume and timing of the streamflow under the present conditions and under the conditions that would exist if the proposed silvicultural activity is implemented. Necessary data for conducting this evaluation is presented in table VIII.4.

Water Available For Streamflow—Existing Conditions

Step 1. — The first step in the hydrologic evaluation of Horse Creek is to estimate the water available for streamflow under the existing conditions. The following details the necessary steps outlined in worksheet III.5. (Numbers in parentheses refer to items or columns on the worksheet.)

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[3] *This is intended to be a fictitious forest; any similarity to an actual forest is entirely coincidental.*

Table VIII.4.--A summary of information required for the analysis procedures, Horse Creek watershed

Description of the information required	Information requirements by chapter[1/]					Information for watershed
	III	IV	V	VI	VII	
						Information on hydrology
Flow--hydrograph or flow duration curve	O					
Bankful				X,P		0.73 cfs
Baseflow					X,P	0.4 cfs
Representative flows to be used to establish suspended and bedload rating curves				X		Worksheet VI.1 Figure VIII.16 , Figure VIII.17
Width stream						
Bankful				X		4.8 ft
Baseflow (average width flowing water)					X	1.5 ft
Depth stream (bankful)				X		0.5 ft
Water surface slope				X		0.005 ft/ft
Suspended sediment for representative flows				X		Figure VIII.17
Bedload sediment for representative flows				X		Worksheet VI.4
Channel stability rating				X		Fair
Orientation stream--azimuth					X	225°
Low flow period (date)					X	2nd week of July
Percent streambed in bedrock					X	90%
Bedrock adjustment factor					P	Figure VII.9 ; 0.18
Length reach exposed					X	530 ft
Travel time through reach					X	20 minutes

[1/] P - Data provided in this handbook
O - Optional data, not required for analysis
X - User-provided data

Table VIII.4.--continued

Description of the information required	Information requirements by chapter					Information for watershed
	III	IV	V	VI	VII	
Information on hydrology--continued						
Normalized hydrographs of potential excess water	P					Figure III.61 and table III.13
Normalized flow duration curves	P					N/A
Date of peak snowmelt discharge	O					June 19th
Map of drainage net	X	X	X	X	X	Figure IV.14 and figure IV.15
Presence of springs or seeps			X			Yes
Change stream geometry						
Water surface slope				X		0.0250 ft/ft
Bankful width				X		2.5 ft
Bankful depth				X		0.8 ft
Information on climate						
Precipitation						
Form	X	O	X			Snow ; maximum snowpack does not exceed 20" water equivalent
Annual average	X					34.3"
Seasonal distribution	X	O				10/1 to 2/28 : 16.1"; 3/1 to 6/30 : 12.1"; 7/1 to 9/30 : 6.1"
Storm intensity and frequency		O	X			May exceed 6"/24 hrs with recurrent interval greater than 10 years
Extreme event						
1 yr, 15-minute storm intensity		X				1.75 in/hr
Drop size		O				N/A
Precipitation--ET relationship	P					Figures III.24 to III.26
Wind direction	X					Northwest

Table VIII.4.--continued

Description of the information required	Information requirements by chapter					Information for watershed
	III	IV	V	VI	VII	
						Information on climate--continued
Snow retention coefficient	X,P					Figure III.6
Date snowmelt begins	0					N/A
Maximum snowmelt rate	0					N/A
Radiation						
Solar ephemeris					P	Figure VII.3
Heat influx					P	Figure VII.7
Iso-erodent map for "R" factor		P				Figure IV.1
						Information on vegetation
Species	X				X	Lodgepole pine
Height						
Overstory	X	X			X	70 ft
Understory		X			X	N/A
Riparian vegetation					X	N/A
Presence phreatophytes			X			N/A
Crown closure (%)					X	65%
Cover density	P	X				33%
Leaf area index (pre)	X					N/A
Basal area	0					$200\ ft^2/acre$
Basal area--C_{dmx} relationship	P					Figure III.41
Ground cover		X				Worksheet IV.2

Table VIII.4.--continued

Description of the information required	Information requirements by chapter					Information for watershed
	III	IV	V	VI	VII	
Information on vegetation--continued						
Percent transmission solar radiation through canopy					X,P	Figure VII.0.1 ; 8%
Percent stream shaded by brush					X	15%
Baseline ET	X,P					Figures III.24 to III.26
ET modifier coefficient	P					Figure III.46
Rooting depth	X					N/A
Rooting depth modifier coefficient	P					N/A
Information on soils and geology						
Depth soil	X		X			Worksheet IV.1 ; 5 ft
Percent sand (0.1-2.0 mm)		X				Worksheet IV.1
Percent silt and very fine sand		X				Worksheet IV.1
Percent clay		X	X			Worksheet IV.1
Percent organic matter		X				Worksheet IV.1
Soil texture		X				Worksheet IV.1
Soil structure		X				Worksheet IV.1
Permeability/Infiltration		X	X			Worksheet IV.1 and worksheet IV.7
Presence of hardpan		X	X			Yes
Nomograph for "K" factor		P				Figure IV.3
Baseline soil-water relationships	X,P					N/A
Soil-water modifier coefficients	P					N/A
Jointing and bedding planes			X			Bedding planes horizontal or dipping into slope; minor joints at angles less than the natural slope; joints may concentrate water.

Table VIII.4.--continued

Description of the information required	Information requirements by chapter					Information for watershed
	III	IV	V	VI	VII	
Information on soils and geology--continued						
Soils map	0	x	x			Figure IV.16
Previous mass movements			x			Worksheet IV.5
Number			x			Figure VIII.15
Location			x			Figure VIII.15
Unit weight dry soil			x			90 lbs/ft^3
Delivery potential			P			Figure V.11
Percent silt and clay delivered			x			24%
Median size coarse material			x			10mm
Information on topography						
Map (hydrologic region)	x	x	x	x	x	USGS map, figure IV.1; Hydrologic region 4
Latitude	x				x	40½°
Size watershed	x					600 acres
Elevation	x					Ranges from 9,100 ft to 11,100 ft
Aspect	x					Southwest
Slope						Average: 30%
Length		x				Worksheet III.2
Gradient		x	x		x	Figure III.13 and worksheet III.2
Dissection			x			500 ft to 300 ft between drainages
Shape/irregularity		x	x			Smooth
Nomograph for "LS" factor		P				Figure III.3

Table VIII.4.--continued

Description of the information required	Information requirements by chapter					Information for watershed
	III	IV	V	VI	VII	
Information on topography--continued						
Surface roughness		X				Moderate to Smooth
Information on the silvicultural activity						
Past history						
Harvesting	X	0				N/A
Fires	X	0				N/A
Other disturbances	X	0				N/A
Proposed harvest						
Location units	X	X				Figure IV.18, worksheet IV.2
Size cuts	X	X				Figure IV.18; 300 acres + 11 acres of roads
Leaf area index removed	X					N/A
Cover density removed	X					100%
Basal area removed	X					100%
Cover density overstory remaining		X				Worksheet IV.2
Cover density understory remaining		X				Worksheet IV.2
Average minimum canopy height		X				0.5 m
Slash and duff--litter		0				N/A
Cover percent		X				Worksheet IV.2
Height	X					2 ft
Percent bare soil		X				Worksheet IV.2

Table VIII.4.--continued

Description of the information required	Information requirements by chapter III	IV	V	VI	VII	Information for watershed
Information on silvicultural activity--continued						
Transportation system						
Area disturbed	x	x				Worksheet IV.2 ; 11.5acres
Location	x	x				Figure IV.17
Cut slopes (location and slope)		x				Worksheet IV.2 ; length 4.8ft ; slope 66.7%
Fill slopes (location and slope)		x				Worksheet IV.2 ; length 4.8ft ; slope 66.7%
Cut and fill vs. full bench		x	x			Cut/fill
Inslope vs. outslope		x				Worksheet IV.2 ; outslope
Surface						
Width		x				12 ft
Gradient		x				Worksheet IV.2 ; 0.0
Surfacing (amount and kind)		x				Worksheet IV.2 ; bare
Road density			x			2% = (11.5 acres roads / 465 acres total)
Harvesting system		x	x			Tractor skidding
Landings						
Location	x	x				Figure IV.17
Size	x	x				Worksheet IV.2
Gradient		x				Worksheet IV.2
Ground cover		x				Worksheet IV.2
Time for vegetative recovery of disturbed surfaces		x				1 year

(1) Watershed name. — Horse Creek can be evaluated as a single hydrologic unit. Division of the basin into hydrologic subunits based upon energy aspect or silvicultural zone is, therefore, unnecessary.

(2) Hydrologic region. — Horse Creek is within hydrologic region 4. Hydrologic regions are described in chapter III.

(3) Total watershed area. — There is one silvicultural prescription for the existing condition with an area of 600 acres.

(4) Dominant aspect. — The most representative aspect for Horse Creek is southwest.

(5) Vegetation type. — Lodgepole pine is the most hydrologically significant vegetation type.

(6) Annual precipitation. — Annual precipitation averages 34.3 inches.

(7) Windward length of open area. — There are no clearcuts on Horse Creek; the watershed is undisturbed.

(8) Tree height. — Average tree height is 70 feet.

(9) Season. — There are three hydrologic sons in region 4: winter (October, November, December, January, February); spring (March, April, May, June); and summer and fall (July, August, September).

(10) Compartment. — Since the area is undisturbed, with no previous silvicultural activity, there are no impacted areas.

(11) Silvicultural state. — Watershed areas are grouped into zones of similar hydrologic response as identified and delineated by silvicultural or vegetational state. For Horse Creek, the only silvicultural state is "forested."

(12) Area, acres. — Horse Creek is undisturbed. There are no meadows or roads within the basin; the watershed is completely forested. Therefore, unimpacted forested area equals the silvicultural prescription area, which is the total watershed area of 600 acres.

(13) Area, %. — This refers to the percentage of watershed area in each silvicultural state. In this case, the unimpacted forested area is 100 percent (1.00 as a decimal percent) of the total watershed area.

(14) Precipitation. — Precipitation averaged 16.1, 12.1, and 6.1 inches for winter, spring, and summer and fall seasons, respectively.

(15) Snow retention coefficient. — Since there are no clearcuts or other open areas within the watershed, snow redistribution is not a factor.

(16) Adjusted snow retention coefficient. — Since snow redistribution is not a factor, there is no adjustment.

(17) Adjusted precipitation. — (No adjustments to the precipitation estimates are necessary.)

(18) ET. — Baseline evapotranspiration (ET) is obtained from figures III.24 to III.26. For Horse Creek, baseline ET is 2.1, 7.6, and 9.2 inches, respectively, for winter, spring, and summer and fall.

(19) Basal area. — The basal area for the forested zone is 200 ft^2/ac.

(20) Cover density, %. — For a basal area of 200 ft^2/ac, figure III.41 gives a cover density of 33 percent.

(21) Cover density,%C_{dmax}. — In the case of Horse Creek, a cover density of 33 percent was judged sufficient for full hydrologic utilization. Therefore, it is considered to be C_{dmax}, so the percentage is 100.

(22) ET modifier coefficient. — The modifier coefficient is 1 for all seasons since the cover density is at C_{dmax}.

(23) Adjusted ET. — (No adjustments are necessary.) Values for Horse Creek are 2.1, 7.6, and 9.2 inches for winter, spring, and summer and fall, respectively.

(24), (25), (26), (27), (28), (29) Water available for streamflow. — The following formula is used to calculate water available for seasonal streamflow by silvicultural state:

$$Q = A\,(P - ET) \qquad \text{(III.15)}$$

where:

Q = water available for seasonal streamflow for a silvicultural activity

A = silvicultural activity area as a decimal percent of the total prescription area [col. (13)]

P = adjusted precipitation inches [col. (17)]

ET = adjusted ET inches [col. (23)]

(30), (31), (32), (33), (34), (35) Water available for annual streamflow. — The sum of water available for streamflow by season represents annual streamflow. For Horse Creek, the unimpacted forested zone generates 14.0 + 4.5 + (−3.1) = 15.4 inches of water available for annual streamflow. (Negative values imply storage depletion.)

Water Available For Streamflow—After Proposed Silvicultural Activity

Step 2. — The second step in the hydrologic evaluation of Horse Creek is to estimate the water available for streamflow if the proposed silvicultural activity is implemented. The following details the necessary steps outlined in worksheet III.6. (Numbers in parentheses refer to the items or columns in the worksheet.)

(1), (2), (3), (4), (5), (6). — Same as worksheet III.5.

(7) Windward length of open area. — All roads and clearcuts on Horse Creek are treated as single clearcuts with a windward length of 6 tree heights and a total area of 311.5 acres (11.5 acres in roads).

(8), (9). — Same as worksheet III.5.

(10) Compartment. — For the proposed condition of Horse Creek, there will be two compartments: impacted and unimpacted. The impacted compartment includes those areas affected (directly or indirectly) by the proposed silvicultural activities, while the unimpacted compartment includes areas unaffected by the proposed silvicultural activities.

(11) Silvicultural state. — For the proposed condition, Horse Creek will have one silvicultural state for the unimpacted compartment (forested) and two for the impacted compartment (forested and clearcut). The set of silvicultural states comprises the single silvicultural prescription for the proposed condition.

(12) Area, acres. — The 135 acres in the northeast corner of the watershed will not be impacted by the proposed silvicultural activity. The remaining 465 acres in the watershed will be directly or indirectly impacted by the proposed silvicultural activity. Trees will be completely removed from 311.5 acres, consisting of 300 acres clearcut and 11.5 acres in roads. The remaining 153.5 impacted acres will not be harvested, but will be affected by snow redistribution. For the purposes of calculation, clearcuts and roads are classified as clearcut (impacted), while the unharvested area affected by snow redistribution is classified as forested (impacted).

(13) Area, %. — Column (12) is divided by item (3) giving decimal percent areas of 0.225, 0.256, and 0.519 for forested (unimpacted), forested (impacted), and clearcut (impacted) areas, respectively.

(14) Precipitation. — This corresponds to column (14) of worksheet III.5.

(15) Snow retention coefficient. — From figure III.6 the snow retention coefficient for a clearcut 6H in windward length is 1.3. The snow retention coefficient for the forest (unimpacted) remains 1.0, while that for the forested (impacted) area is not defined by figure III.6.

(16) Adjusted snow retention coefficient. — For the forested (unimpacted) area, it is assumed that there is no net change in precipitation from snow redistribution. The adjusted snow retention coefficient for the clearcut area is determined by weighting the snow retention coefficient as follows:

$$\rho_{oadj} = 1 + (\rho_o - 1)\,\frac{0.50}{X} \qquad \text{(III.3)}$$

where:

ρ_{oadj} = adjusted snow retention coefficient for the clearcut area

ρ_o = snow retention coefficient from figure III.6 = 1.3

$$X = \frac{\text{clearcut area (including roads)}}{\text{total impacted area}}$$

This is the percent of impacted area to be clearcut. Substituting values:

$$X = \frac{311.5 \text{ ac}}{(311.5 \text{ ac} + 153.5 \text{ ac})}$$

Substituting values for Horse Creek:

$$\rho_{oadj} = 1 + (1.3 - 1)\left[\frac{0.50}{311.5/(311.5 + 153.5)}\right] = 1.22$$

The adjusted snow retention coefficient for the forested area in the impacted compartment is calculated using the following formula:

$$\rho_f = \frac{1 - \rho_{oadj}X}{1 - X} \qquad \text{(III.13)}$$

where:

ρ_f = adjusted snow retention coefficient for the impacted forested area

ρ_{oadj} = adjusted snow retention coefficient for the clearcut = 1.22

$$X = \frac{\text{clearcut area (including roads)}}{\text{total impacted area}}$$

This is the percent of impacted area to be clearcut. Substituting values:

$$X = \frac{311.5 \text{ ac}}{(311.5 \text{ ac} + 153.5 \text{ ac})}$$

Substituting values for Horse Creek:

$$\rho_f = \frac{1 - [(1.22)\ ((311.5)/(311.5 + 153.5))\ ]}{1 - [311.5/(311.5 + 153.5)]}$$

$$= 0.55$$

(17) Adjusted precipitation. — Multiplying the precipitation value in column (14) by the adjusted snow retention coefficient in column (16) gives adjusted precipitation. For example, the adjusted precipitation for the clearcut area of Horse Creek is 16.1 × 1.22 = 19.6 inches.

(18) ET. — Same instruction as worksheet III.5.

(19) Basal area. — For forested areas, the basal area greater than 4 in dbh is 200 ft^2/ac, while the clearcut basal area greater than 4 inches dbh is zero. These data are needed to estimate cover density, if cover density is not supplied by the user.

(20) Cover density. — For a basal area of 200 ft^2/ac, figure III.41 gives a cover density of 33 percent. For a basal area of zero, the cover density is zero.

(21) Cover density,$\%C_{dmax}$. — A cover density of 33 percent has been judged sufficient for full hydrologic utilization and has been assigned the value of C_{dmax}. Division of cover density percent in column (17) by C_{dmax} gives $\%C_{dmax}$ when multiplied by 100.

(22) ET modifier coefficient. — The $\%C_{dmax}$ can be entered into figure III.46 to obtain the ET modifier coefficient. For a $\%C_{dmax}$ of 100, figure III.46 gives ET modifier coefficients of 1.0 for all seasons. For a $\%C_{dmax}$ of zero, the ET mdifier coefficients from figure III.46 are 0.60, 107, and 0.55 for winter, spring, and summer and fall, respectively.

(23) Adjusted ET. — Multiplying ET in column (18) by the ET modifier coefficient in column (22) yields the adjusted ET.

(24), (25), (26), (27), (28), (29) Water available for streamflow. — Multiplication of the treatment area (as a decimal percentage of the watershed area, item 13) times the difference between adjusted precipitation and adjusted evapotranspiration (item 17- item 23) is an estimate of area weighted contribution to total watershed flow that will be derived from the treatment (or state) area by season and is entered in one of the columns from 24-29.

For example, for the clearcut in winter:

$$Q = 0.519(19.6-1.3) = 9.5 \text{ inches}$$

(30), (31), (32), (33), (34), (35) Water available for annual streamflow. — The summation of seasonal streamflows is an estimate of the water available for annual streamflow. Horse Creek values are 3.5, 1.1, and 13.5 inches for the (unimpacted) forested, (impacted) forested, and clearcut areas, respectively.

Streamflow Discharge And Timing — Existing Conditions

Step 3. — The third step in the hydrologic evaluation of Horse Creek is to estimate the discharge and timing of the existing condition. The following details the necessary steps outlined in worksheet III.7. (Numbers in parentheses refer to the items or columns in the worksheet.)

(1), (2). — Same as worksheet III.5 and III.6.

(3) Date or interval. — Based on previous knowledge of the area, peak discharge for Horse Creek occurs June 19. Six-day intervals centered around this date are listed in column (3).

(4) Forested (unimpacted),%. — Values from the forested column of table III.13 are entered into column (4) with a peak discharge of 0.1575 percent occurring on June 19.

(5) Forested (unimpacted), inches. — Forested, (unimpacted), percent [col. (4)] is multiplied by potential streamflow for the existing condition from the forested (unimpacted) zone [item (30), wksht III.5] which is 15.4 inches.

(6) Forested (unimpacted), cfs. — Each value in column (5) forested (unimpacted) in inches, is multiplied by the following factor:

$$\frac{\text{total watershed area (ac)}}{(12 \text{ in/ft})\ (1.98)\ (\text{number of days in interval})}$$

For example, on May 26, 0.92 inches is converted to cfs as follows:

$$\text{cfs} = \frac{(600)\ (0.92)}{(12)\ (1.98)\ (6)} = 3.87 \text{ cfs}$$

(7) - (21). — Not applicable to the existing condition of Horse Creek.

(22) Composite hydrograph. — The sum of columns (6), (9), (12), (15), (18), and (21) gives the composite hydrograph in digital form. A plot of column (3) versus column (22) yields the existing condition hydrograph (fig. VIII.13).

Streamflow Discharge And Timing — After Proposed Silvicultural Activity

Step 4. — The final step in the hydrologic evaluation of Horse Creek is to estimate the discharge and timing of the streamflow if the proposed silvicultural activity is implemented. The following details the necessary steps outlined in worksheet III.8. (Numbers in parentheses refer to the items or columns on the worksheet.)

(1), (2). — Same as worksheet III.5, III.6, and III.7.

(3) Date or interval. — The date of peak snowmelt discharge for Horse Creek is June 19, the peak discharge date for the forested (unimpacted) zone. Six-day intervals are labeled accordingly.

(4) Forested (unimpacted), %. — Same instructions as worksheet III.7.

(5) Forested (unimpacted), inches. — Column (4) is multiplied by potential streamflow for the proposed condition from the forested (unimpacted) zone [item (25), wksht. III.6]. For Horse Creek this value is 3.5 inches.

(6) Forested (unimpacted), cfs. — Each value in column (5), is multiplied by the following factor:

$$\frac{\text{total watershed area (ac)}}{\text{(12 in/ft) (1.98) (number of days in interval)}}$$

$$= \frac{600}{(12)\ (1.98)\ (6)} = 4.209$$

(7), (8), (9). — Not applicable for the Horse Creek example.

(10) Forested (impacted),%. — These values are taken from the forested column in table III.13.

(11) Forested (impacted), inches. — Column (10) is multiplied by potential streamflow for the proposed condition from the forested (impacted) zone [item (32), wksht. III.6]. For Horse Creek this value is 1.1 inches.

(12) Forested (impacted), cfs. — Conversion of inches to cfs involves multiplication of each value in column (11) by:

$$\frac{\text{total watershed area (ac)}}{\text{(12 in/ft) (1.98) (number of days in interval)}}$$

$$= \frac{600}{(12)\ (1.98)\ (6)} = 4.209$$

(13) Clearcut (impacted),%. — Percent potential streamflow distribution for open areas is taken from the open column of table III.15. Note that peak discharge from clearcut areas occurs before peak discharge from forested areas.

(14) Clearcut (impacted), inches. — Column (13) is multiplied by potential streamflow for the proposed condition from the open (impacted) zone [item (33), wksht. III.6]. For Horse Creek this value is 13.5 inches.

(15) Clearcut (impacted), cfs. — Convert inches to cfs by multiplying values in column (14) by the factor:

$$\frac{\text{total watershed area (ac)}}{\text{(12 in/ft) (1.98) (number of days in interval)}}$$

$$= \frac{600}{(12)\ (1.98)\ (6)} = 4.209$$

(16) - (21). — Not applicable for the Horse Creek example.

(22) Composite hydrograph. — The sum of columns (6), (9), (12), (15), (18), and (21) for each interval gives the composite hydrograph for the entire Horse Creek watershed (in cfs) (fig. VIII.13).

SURFACE EROSION ANALYSIS

The quantity of surface eroded material delivered to stream channels from sites disturbed by the proposed silvicultural activities is estimated in two stages. First, the quantity of material that may be made available from a disturbed site is estimated using the Modified Soil Loss Equation (MSLE). Second, a sediment delivery index (SD_I) is estimated. When this is applied to the estimated quantity of available surface eroded material, an estimate of the quantity of material that may enter a stream channel is obtained.

Erosion Response Unit Delineation

Steps 1-7. — A method for preparing the maps (or overlays) for these steps is discussed in chapter IV. Figures IV.14 to IV.19 show the results of these steps for the drainage net, hydrographic areas, soil

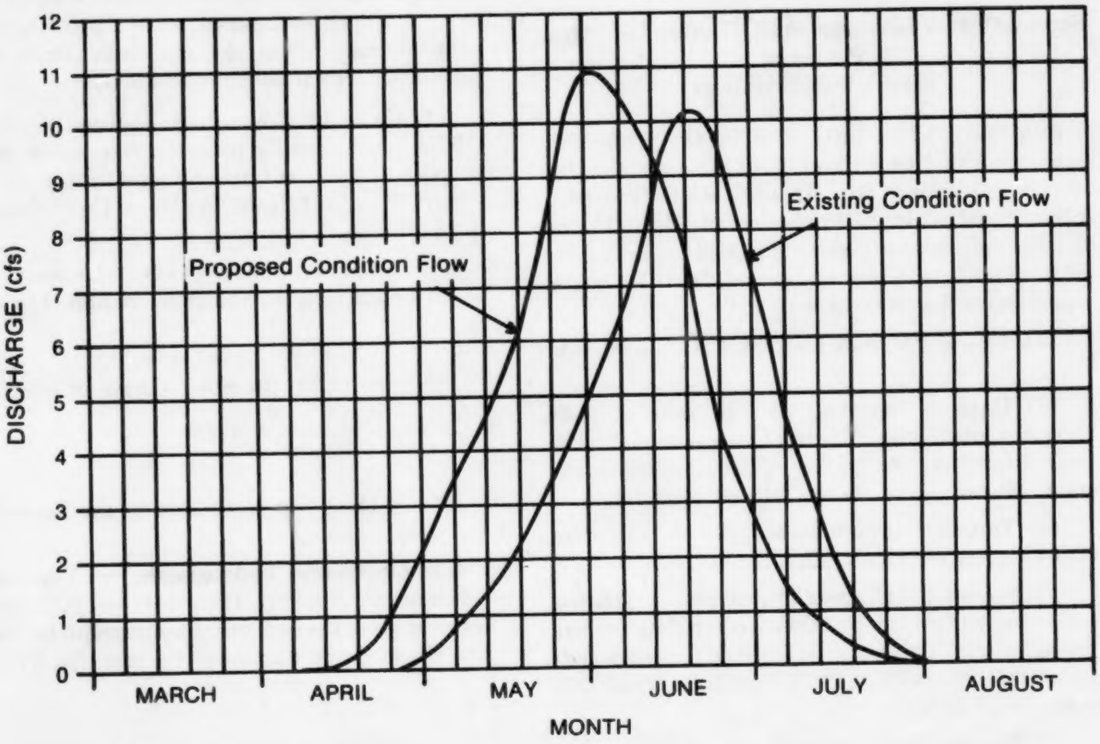

Figure VIII.13.—Pre- and post-silvicultural activities annual hydrograph, Horse Creek watershed.

groups, location of cutting units, roads, and landings.

Step 8. — Set up worksheets for estimating potential sediment load from surface erosion.

Worksheets IV.1 and IV.2 show field data for erosion response units by hydrographic area and type of disturbance. Individual soils in the Horse Creek watershed have been grouped according to similar texture, organic matter, structure, and permeability characteristics. Worksheet IV.1 shows the three soil groups used for surface erosion evaluation. Data on worksheet IV.1 should not change when different management proposals are evaluated for the watershed.

Worksheet IV.2 displays various types of data needed for evaluating the effects of the proposed management of Horse Creek watershed, hydrographic area 3 (fig. IV.15). Individual erosion response units are identified and listed. A different erosion response unit is created for each change in management activity, each design change for a given activity (e.g., road change from a cut-and-fill design to a complete fill for a stream crossing), or each change in environmental parameters affecting erosion (e.g., a change in soil characteristics).

Worksheet IV.3 is a summary of the values used in the MSLE and sediment index for erosion response units in hydrographic area 3 of the Horse Creek watershed. The values for both management proposals are obtained using the steps and discussions which follow. Only values for the proposed plan are used to illustrate methods for solving the equations; however, values for the revised plan are similarly determined

Step 9. — List each erosion source area and number by erosion response unit.

For the Horse Creek watershed, the response units have been coded as follows. The treatment types are clearcuts (CC), landings (L), and roads (R). The example hydrographic area is number 3. Disturbance types are numbered sequentially (e.g., clearcut CC3.1, clearcut CC3.2, etc). to identify them in the following evaluations for soil loss and sediment delivery.

Using The Modified Soil Loss Equation (MSLE)

Step 10. — For each erosion response unit and source area (silvicultural activities and roads), determine the values to be used for each of the following variables:

R - Rainfall factor
K - Soil erodibility factor
LS - Length-slope factor
VM - Vegetation-management factor
Area - Surface area of response unit

Values for these factors are entered on worksheet IV.3 using the following procedures.

Rainfall Factor

This value is obtained from figure IV.2. For the Horse Creek area, $R = 45$. This R value is the same over the entire Horse Creek area and will be used for all erosion response units.

Soil Erodibility Factor

The K value can be estimated using the nomograph in figure IV.3, or by using equation IV.4. The data for soil group 2 needed to compute the K value using equation IV.4 are found on worksheet IV.1. K must be determined for both topsoil and subsoil. For disturbances which enter the subsoil, such as roads, the subsoil value of K must be used.

Application of the equation to determine the K factor is shown in the following example for soil group 2 topsoil. This example is also plotted on the nomograph (fig. IV.3) for the subsoil. Because of inflections in the family of curves on the nomograph (fig. IV.3) for percent sand, the equation cannot be used when silt plus very fine sand exceed 70 percent.

$$K = (2.1 \times 10^{-6})\ (12\text{-Om})\ M^{1.14} + 0.0325\ (S\text{-}2) + 0.025\ (P\text{-}3) \qquad \text{(IV.4)}$$

where:

Om = % organic matter
M = (% silt + % very fine sand) (100 − % clay)
S = structure code
P = permeability code

Substituting values for topsoil (soil group 2) from worksheet IV.1 into equation IV.4:

$$K = (2.1 \times 10^{-6})\ (12\text{-}4)\ [40\ (100\text{-}10)]^{1.14} + 0.0325\ (4\text{-}2) + 0.025\ (4\text{-}3)$$

$$K = 0.28$$

The K value of the subsoil (0.30) may be determined from either the nomograph or equation.

Length-Slope Factor

The length-slope factor, LS, is a combination factor which incorporates the slope gradient and the length of the eroding surface into a single factor. The LS factor must be estimated for each erosion response unit.

Two methods may be used to estimate the LS factor on straight slopes. One method is to use equation IV.8 to derive the estimated LS value. The second method utilizes a nomograph (fig. IV.4) to estimate the LS value.

The cutting units (CC3.1 and CC3.2) are each different in regard to slope gradient and length. Therefore, LS for each clearcut unit must be evaluated separately. Using equation IV.8 and data from worksheet IV.2, the LS value for CC3.1 is calculated as follows for slope length $\lambda = 100$ feet and slope gradient $s = 38$ percent.

$$LS = \left(\frac{\lambda}{72.6}\right)^{m} \left(\frac{0.43 + 0.30s + 0.043s^2}{6.613}\right) \left(\frac{10{,}000}{10{,}000 + s^2}\right) \qquad \text{(IV.8)}$$

where:

λ = slope length, in feet

s = slope gradient, in percent

m = an exponent based on slope gradient from equation IV.6

Using data from worksheet IV.2:

$$LS = \left(\frac{100}{72.6}\right)^{0.5} \left(\frac{0.43 + 0.30(38) + 0.043(38)^2}{6.613}\right) \left(\frac{10{,}000}{10{,}000 + (38)^2}\right)$$

$$LS = 11.5$$

A similar calculation is performed for clearcut CC3.2 and landing L3.1. All values are tabulated in worksheet IV.3.

Road R3.1 is outsloped with a typical cross section shown in figure IV.7. Road R3.2 is assumed to be fill, over culverts. Average dimensions will be the same as for R3.1 with the cutbank changed to a fill slope.

To compute the length-slope value for the road sections (R3.1, R3.2,) the equation for irregular slopes is used in this example. An alternative method using graphs (figs. IV.5 and IV.6) is discussed in chapter IV.

$$LS = \frac{1}{\lambda_e} \cdot \sum_{j=1}^{n} \left[\left(\frac{S_j \lambda_j^{m+1}}{72.6^m} - \frac{S_j \lambda_{j-1}^{m+1}}{72.6^m} \right) \left(\frac{10{,}000}{10{,}000 + s_j^2} \right) \right] \qquad \text{(IV.9)}$$

The number of calculations can be reduced by simplifying equation IV.9 to:

$$LS = \frac{1}{\lambda_e} \cdot \sum_{j-1}^{n} \left[S_j \left(\frac{\lambda_j^{m+1} - \lambda_{j-1}^{m+1}}{72.6^m} \right) \left(\frac{10{,}000}{10{,}000 + s_j^2} \right) \right] \qquad \text{(IV.9.1)}$$

where:

λ_e = entire length of a slope, in feet

λ_j = length of slope to lower edge of j segment, in feet

j = slope segment

s_j = slope gradient, in percent

S_j = dimensionless slope steepness factor for segment j defined by:

$$(0.043s_j^2 + 0.30s_j + 0.43)/6.613$$

m = an exponent based on slope gradient

n = total number of slope segments

For the road R3.1, using values in worksheet IV.2 and assuming that no sediment is deposited on the road surface, the computations are as follows:

Slope segment 1 (cut)

λ_1 = 4.8 ft

$\lambda_{1\text{-}1}$ = 0.0 ft (there are no preceding slope segments, hence length is 0.0 ft)

s = 66.7%

m = 0.6 (for slopes on construction; see eq. IV.6)

$$S_1 = \frac{0.043s^2 + 0.30s + 0.43}{6.613}$$

substituting for s:

$$S_1 = \frac{0.043(66.7)^2 + 0.30(66.7) + 0.43}{6.613} = 32$$

Substituting values of S, λ, and m for j=1 into equation IV.9.1 to the right of the summation sign gives:

$$32\left(\frac{(4.8)^{1.6} - (0)^{1.6}}{(72.6)^{0.6}}\right)\left(\frac{10{,}000}{10{,}000 + (66.7)^2}\right)$$

$$= 20.83$$

Slope segment 2 (roadbed)

λ_2 = 4.8 + 12.0 = 16.8 ft

$\lambda_{2\text{-}1}$ = slope length = 4.8 ft

s = 0.5%

m = 0.6 (for slopes on construction sites)

$$S_2 = \frac{0.043s^2 + 0.30s + 0.43}{6.613}$$

substituting for s:

$$S_2 = \frac{0.043(0.5)^2 + 0.30(0.5) + 0.43}{6.613} = 0.09$$

Substituting S, λ, and m values for j=2 into equation IV.9.1 to the right side of the summation sign gives:

$$0.09\left(\frac{(16.8)^{1.6} - (4.8)^{1.6}}{(72.6)^{0.6}}\right)\left(\frac{10{,}000}{10{,}000 + 0.5^2}\right)$$

$$= 0.54$$

Slope segment 3 (fill)

λ_3 = 4.8 + 12.0 + 4.8 = 21.6 ft

$\lambda_{3\text{-}1}$ = slope length = 16.8 ft

s = 66.7%

m = 0.6 (for slopes on construction sites)

$$S_3 = \frac{0.043s^2 + 0.30s + 0.43}{6.613}$$

substituting for s:

$$S_3 = \frac{0.043(66.7)^2 + 0.30(66.7) + 0.43}{6.613} = 32$$

Substituting S, λ, and m values for j=3 into equation IV.9.1 to the right side of the summation sign gives:

$$32\left(\frac{(21.6)^{1.6} - (16.8)^{1.6}}{(72.6)^{0.6}}\right)\left(\frac{10{,}000}{10{,}000 + (66.7)^2}\right)$$

$$= 76.53$$

Solving the entire equation IV.9.1, using the calculated values

where:

λ_e = 4.8 + 12.0 + 4.8 = 21.6 ft

then:

$$LS = \frac{1}{\lambda_e}(\text{slope seg. } 1 + \text{slope seg. } 2 + \text{slope seg. } 3)$$

$$= \frac{1}{21.6}\ (20.83 + 0.54 + 76.53)$$

$$= 4.53$$

A similar LS calculation is made for road R3.2. Road R3.2 is a fill, over culverts across a stream channel, however, and it becomes two problems, each with two slope segments. Each segment starts at the middle of the road surface, and the second segment includes one of the fill slopes. An average value (4.3) for the LS factor using the two LS values just determined by splitting the road in half is entered on worksheet IV.3.

Vegetation-Management Factor

The vegetation-management factor (VM) is used to evaluate effects of cover and land management practices on surface erosion over the entire slope length used for the LS factor. Values for VM are determined for all cutting units, roads, and landings.

(1) Cutting units. — Worksheet IV.2 has the field data used for calculating a VM factor for clearcut units CC3.1 and CC3.2. Example calculations are shown for clearcut CC3.1. The cutting unit is divided into two areas based on presence or absence of logging residues. A ground cover of slash and other surface residues covers 65 percent of the unit (wksht. IV.2). The remaining 35 percent is scattered in open areas of soil averaging 10 feet in diameter.[4] In both areas, fine tree roots are uniformly distributed over 90 percent of the clearcut block. All of the overstory and understory canopy has been removed.

Using worksheet IV.4, first enter percent area as 0.65 and 0.35 for area covered by residues and open area, respectively. Separate calculations are made for the logging residue and open areas.

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[4] *Information about the amount of residue is often expressed in tons per acre. Maxwell and Ward (1976) have published photos and tables for parts of Oregon and Washington which relate visual appearance of a site with the volume of residue and amount of ground cover.*

Second, the logging slash represents the mulch and close growing vegetation. Because slash varies in density, assume that small openings a few inches in diameter exist over 10 percent of the surface. From figure IV.9, the 90-percent cover provides a mulch factor of 0.08. The 35 percent of CC3.1 that is open is assumed to have 10 percent of the surface protected by widely scattered slash. Using figure IV.9, a mulch factor of 0.78 is found for this situation.

Third, zero canopy cover gives a canopy factor of 1.0 for both areas (fig. IV.8).

Fourth, evaluate the role of fine roots that are remaining in the soil. Since they are uniformly distributed over 90 percent of the entire clearcut area, the value, 0.10, from figure IV. 10 can be used for both logging residue and bare areas.

Fifth, determine if the open areas are connected with each other, such that water can flow downslope from one to another (ch. IV). In this example, the open areas are isolated from each other by bands of logging residue, requiring the use of a sediment filter strip factor of 0.5 (see "Sediment Filter Strips" section of chapter IV). If sediment filter strips did not exist, a factor of 1.0 would be used.

Sixth, using worksheet IV.4, multiply the VM subfactors for logging residue (0.65) (0.08) (1.0) (0.10) = 0.005. Likewise, the subfactors for bare area are: (0.35) (0.78) (1.0) (0.1) (0.5) = 0.014. The overall VM factor is the sum of the VM subfactors: (0.005) + (0.014) = 0.019.

Clearcut CC3.2 will have 60-percent logging residue cover and 40-percent bare, with bare areas averaging 10 feet in diameter. Fine roots will be uniformly distributed over 85 percent of both areas. There will not be any canopy. Bare areas will have filter strips between them. The assumptions about residue density are the same as for CC3.1. Values are shown on worksheet IV.4.

(2) Landings. — Landing L3.1 is assumed to represent a surface described in table IV.3 as "freshly disked after one rain," with a VM factor of 0.89.

(3) Roads. — The VM factor must represent two conditions on the road areas: (1) the road running surface, and (2) the cut-and-fill banks that are needed (fig. IV.7).

The following assumptions have been made for road erosion response units R3.1 and R3.2.

a. All cut-and-fill slopes will be seeded and fertilized within 10 days after completion of the road section.

b. Vegetation will be fully established within 1 year.

During the first year, the VM factor will be changing constantly from bare soil to a vegetated surface on the cut-and-fill slopes. To account for this change, VM is estimated monthly; total those months with erosive rainfall or runoff, and then divide by the total number of erosion months to obtain an average VM value for those time periods with potential for erosive rainfall and/or snowmelt runoff (wksht. IV.5). Use the method described for clearcuts to estimate VM for the site by month. The VM factor will be effected initially by the ground cover (fig. IV.9). As the vegetation matures, canopy and fine roots will also influence the VM factor.

Summing the VM values from worksheet IV.5 and dividing by 8 months (3.36/8 = 0.42) gives a VM value of 0.42 to use for the first year following construction with cut-and-fill slopes.

The VM for the roadbed (1.24) for R3.1 is obtained from table IV.3 for compacted fill without surfacing.

$$\text{Total width for exposed surface} = 2.9\text{ ft} + 12\text{ ft} + 2.9\text{ ft}$$

$$= 17.8\text{ ft}$$

$$\text{Running surface} = \frac{12.0\text{ ft}}{17.8\text{ ft}} = 0.6742$$

$$= \text{fraction of total width}$$

$$\text{Each cut or fill slope} = \frac{2.9\text{ ft}}{17.8\text{ ft}} = 0.1629$$

$$= \text{fraction of total width}$$

The weighted VM factor for R1.1 and R1.2 is calculated from data on worksheet IV.2 and shown on worksheet IV.6.

Surface Area Of Response Unit

Total surface area within each treatment unit—clearcuts, landings, and roads—is given in worksheet IV.2 and is entered onto worksheet IV.3. All other MSLE factors are also entered onto worksheet IV.3. Total potential onsite soil loss is computed by multiplying all factors on worksheet IV.3.

Sediment Delivery

Step 12. — The computed potential surface soil loss is delivered to the closest stream channel using the sediment delivery index (SD_I). Worksheet IV.7 is used to organize the data for each erosion response unit, for each factor shown on the stiff diagram (fig. IV.22).

1. Water availability for sediment delivery is calculated using equation IV.12 for each erosion response unit.

$$F = CRL \qquad \text{(IV.12)}$$

where:

F = available water (ft^3/sec)

R = [1 yr, 15 min storm (in/hr)] − [soil infiltration rate (in/hr)]

L = [slope length distance of disturbance (ft)] + [slope length from disturbance to stream (ft)]

$C = 2.31 \times 10^{-5} \dfrac{\text{ft}^2\ \text{hr}}{\text{in sec}}$

The infiltration rate, used in determining the R factor, is the maximum rate at which water could enter a soil. In actual situations, the water entry rate will usually be somewhat lower than the infiltration rate and can be based on the soil permeability, with consideration for effects of various management practices.

Using data from worksheet IV.2 and footnotes from worksheet IV.7, the calculations are:

$$\begin{aligned} F &= \left(2.31 \times 10^{-5} \frac{\text{ft}^2\ \text{hr}}{\text{in sec}}\right) (1.75 \text{ in/hr} \\ &\quad - 0.26 \text{ in/hr})\ (100 \text{ ft} + 15 \text{ ft}) \\ &= (2.31 \times 10^{-5})\ (1.49)\ (115) \\ &= 0.004 \text{ ft}^3/\text{sec} \end{aligned}$$

2. Texture of eroded material is based on the amount of very fine sand, silt, and clay shown on worksheet IV.1. For this case, it has been assumed that half of the clay will form stable aggregates with the remainder influencing the sediment delivery index. For soil group 2 topsoil, the following calculations were made:

$$\begin{aligned} \text{texture of eroded material} &= \frac{\%\ \text{clay}}{2} + \%\ \text{silt} \\ &\quad + \%\ \text{very fine sand} \\ &= \frac{10}{2} + (15) + (25) \\ &= 45 \end{aligned}$$

3. Ground cover is the percentage of the soil surface with vegetative residues and stems in direct contact with the soil. The ground cover on the area between a disturbance and a stream channel is determined from field observations and used for the sediment delivery index. For CC3.1, 90 percent is shown on worksheet IV.2 for ground cover.
4. Slope shape is a subjective evaluation of shapes between convex and concave. From worksheet IV.2 for CC3.1 the slope shape is straight.
5. Distance is the slope length from the edge of a disturbance to a stream channel. For CC3.1 (wksht. IV.2), the distance is 15 feet.
6. Surface roughness is a subjective evaluation of soil surface microrelief ranging from smooth to moderately rough. Worksheet IV.2 shows a moderate surface roughness for CC3.1.
7. Slope gradient is the percent slope between the lower boundary of the disturbed area and the stream channel. Worksheet IV.2 shows a gradient of 38 percent for the disturbed area.
8. Site specific is an optional factor that was not used in this example. See chapter IV for more discussion of this factor.

The tabulated factors for CC3.1 (wksht. IV.7) are plotted on the appropriate vectors of a stiff diagram (fig. VIII.14) as discussed in chapter IV. Use one of the several methods to determine the area bounded by the irregular polygon that is created when points on the stiff diagram are joined. The area of the polygon for this example is 94.94 square units. The stiff diagram has 784 square units. The percentage of the total area enclosed by the polygon is:

$$\left(\frac{94.94}{784}\right)\left(100\right) = 12.1\%$$

Entering the X-axis of the probit curve (fig. IV.23) with 12.1 results in a sediment delivery index (SD_I) or 0.02. This is the estimated fraction of eroded material that could be delivered from the disturbance to the stream channel.

Step 13. — Find the estimated quantity of sediment (tons/yr) delivered to a stream channel by multiplying surface soil loss by the sediment delivery index (wksht. IV.3) for each erosion response unit.

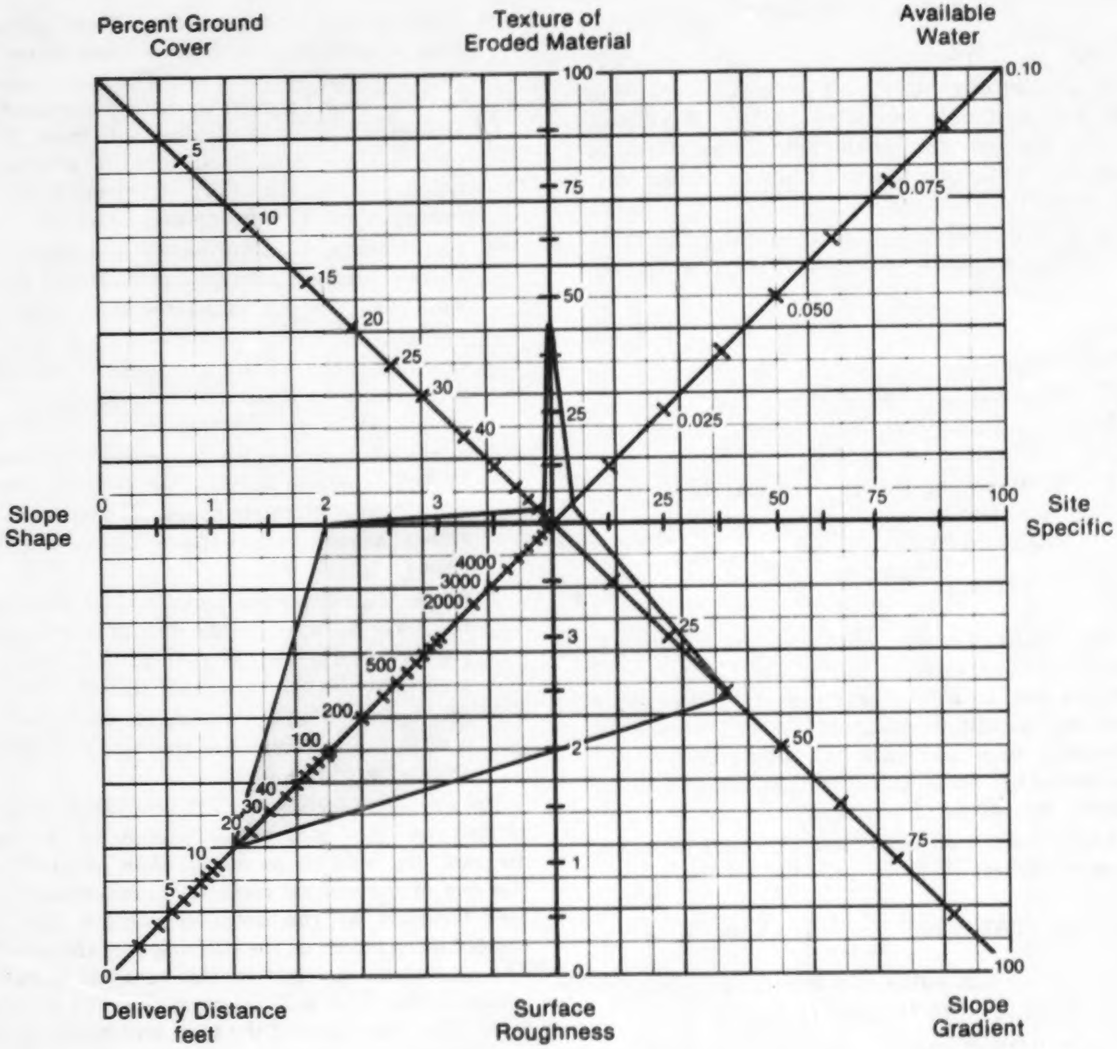

Figure VIII.14.—Stiff diagram for CC3.1 proposed plan, Horse Creek watershed.

Step 14. — Using worksheet IV.8, tabulate quantities of delivered sediment (tons/yr) for each hydrographic area by the erosion source. When completed, this table provides a summary of surface erosion sources and estimated quantities of sediment production from each hydrographic area.

Step 15. — Totals and percentages are shown on worksheet IV.8. The total quantity of delivered material is shown in table VIII.5.

SOIL MASS MOVEMENT ANALYSIS

A step-by-step description, using the Horse Creek data, was presented in "Chapter V: Soil Mass Movement." The following discussion summarizes the results of that detailed description.

Evaluation of the existing soil mass movement hazard (fig. VIII.15) in the Horse Creek drainage is based upon seven natural site factors using table V.5 and worksheet V.1. Based upon the information collected and presented in the beginning of the example, the natural soil mass movement hazard index is medium, with a factor summation of 31. The value 31 falls within the medium hazard range (21-44).

The proposed silvicultural activity will result in an increased soil mass movement hazard. Worksheet V.2 is completed based upon the proposed silvicultural activity. The information required to complete this worksheet is presented in table VIII.4. The three silvicultural activity factors total 31. Adding the existing natural hazard value of 31 to the silvicultural activity hazard value of 31 gives the total value for the post-silvicultural activity: 62. This value falls within the high hazard range (greater than 44).

There is evidence of one soil mass movement in Horse Creek watershed approximately 20 years ago on a smooth 67 percent (34°) slope. The dimensions of the failure are 84 feet long, 28 feet wide, and 1.5 feet deep. The bulk density was found to be 90 lbs/ft^3 (1.43g/cm^3).

To evaluate the potential impact of the proposed silvicultural activity on soil mass movement, Horse Creek must be compared to an adjacent watershed, Mule Creek. Mule Creek, which had a silvicultural activity similar to that proposed for Horse Creek, was investigated to ascertain the actual impacts that followed a silvicultural activity. Mule Creek watershed is considerably larger than Horse Creek—3,900 acres vs. 600 acres (1,620 ha vs. 243 ha)—however, both watersheds have similar site characteristics—soils, geology, precipitation, vegetation, etc. Prior to the silvicultural activity in Mule Creek, there had been only one soil mass movement (debris avalanche-debris flow), approximately 25 years ago, on a smooth 84 percent (40°) slope-length 115 feet, width 19 feet, depth 1.5 feet and bulk density 99 lbs/ft^3. During the 4 years since the silvicultural activity, five debris avalanche-debris flows have occurred:

1. Smooth 73 percent (36°) slope—length 80 feet, width 24 feet, and depth 1.5 feet.
2. Smooth 73 percent (36°) slope—length 129 feet, width 26 feet, and depth 1.5 feet.
3. Smooth 55 percent (29°) slope—length 121 feet, width 17 feet, and depth 1.5 feet.
4. Smooth 55 percent (29°) slope—length 113 feet, width 18 feet, and depth 1.5 feet.
5. Smooth 40 percent (22°) slope—length 95 feet, width 23 feet, and depth 1.5 feet.

Using the procedure outlined in chapter V and figure V.8, worksheets V.1, V.2, V.5, and V.6 were completed. Based upon these computations, it was determined that 192 tons of soil mass movement material could potentially be delivered to Horse Creek due to the proposed silvicultural activity. This total is shown on table VIII.5.

TOTAL POTENTIAL SEDIMENT ANALYSIS

Step 1. — The stream reach characterization will be obtained on the lower 1/4 mile of the third-order stream channel on Horse Creek.

Step 2. — See figure VIII.13 pre- and post-silvicultural activity hydrographs.

Suspended Sediment Calculation

Step 3. — Establish suspended sediment rating curve.

a. Data were obtained from depth integrated suspended sediment sampling and concurrent stream discharge measurements taken over a period of 1 year. Samples were taken during representative flows and are plotted in figure VIII.16.

Table VIII.5

Summary of quantitative outputs for: Proposed plan, Horse Creek

Chapter	Line No.	Output description		Computed value		Chapter reference (worksheets)
				Pre-activity	Post-activity	
Hydrology: Chapter III	1	Water available for annual streamflow		15.4 in	18.1 in	III.5, III.6
	2	Increase in water available for annual streamflow			2.7 in	III.5, III.6
	3	Peak discharge		10.2 cfs	10.99 cfs	III.7, III.8
	4	Date of peak discharge		June 15	June 1	III.7, III.8
	5	Hydrograph				
	6	7-day flow duration curve		N.A.	N.A.	
Surface Erosion: Chapter IV	7	Surface soil loss		N.A.	780 tons/yr	IV.3
	8	Sediment delivered to stream channel		N.A.	17.7 tons/yr	IV.8
Soil Mass Movement: Chapter V	9	Hazard index		31	62	V.1, V.2
	10	Weight of sediment	Coarse >0.062 mm	N.A.	122 tons/yr	
	11		Fine <0.062 mm	N.A.	70 tons/yr	
	12		Total	N.A.	192 tons/yr	V.6
	13	Acceleration factor			3	V.6
Total Potential Sediment: Chapter VI	14	Sediment discharge due to flow change	Bedload	1.4 tons/yr	1.9 tons/yr	VI.3 line E VI.3 line F
	15		Suspended	7.1 tons/yr	8.8 tons/yr	VI.3 line A VI.3 line B
	16		Total	8.5 tons/yr	10.7 tons/yr	VI.3 line K VI.3 line G
	17	Total suspended sediment discharge from all sources		7.1 tons/yr	72.5 tons/yr	VI.3 line A line I.1 + A
	18	Increase in total potential bedload plus suspended sediment from all sources			211.9 tons/yr	VI.3 line M
Temperature: Chapter VII	19	Potential temperature changes			1.9 °F	VIII.2

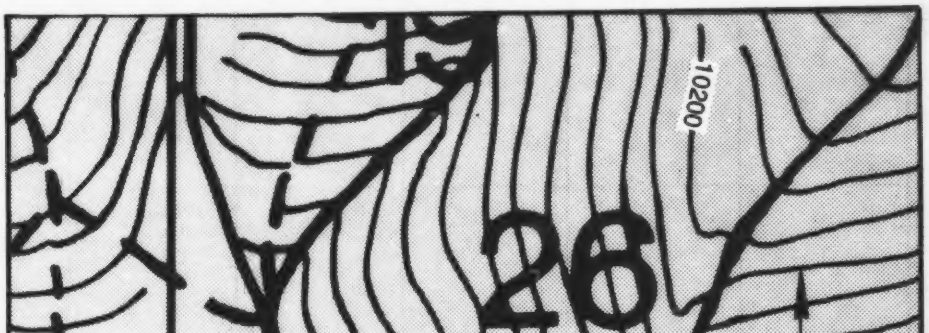

Figure VIII.15.—Horse Creek drainage showing potential areas of mass movement.

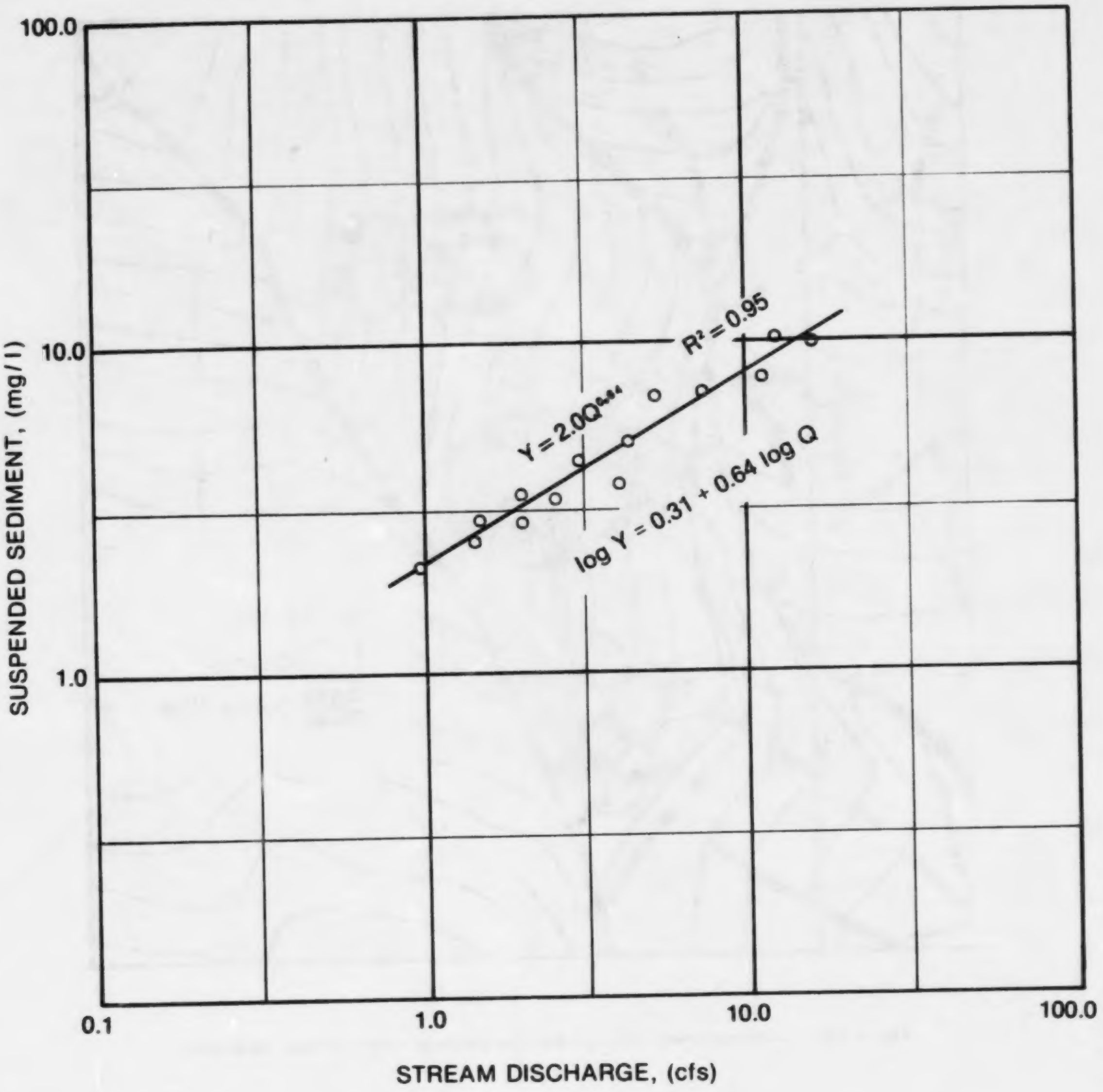

Figure VIII.16.—Sediment rating curve, Horse Creek watershed.

b. log Y = 0.31 + 0.64 log Q
   r^2 = 0.95: coefficient of determination. See figure VIII.16 for plot of data.

c. The channel stability rating procedure by Pfankuch (1975) was used to obtain a fair rating.

Step 4. — Calculate pre-silvicultural activity potential suspended sediment discharge. See figure VIII.13 for pre- and post-silvicultural activity hydrographs. Use data from worksheet VI.1.

a. Use worksheet VI.1, columns (1), (2), (3), and (4).

b. Record the total of 7.1 tons/yr on worksheet VI.3, line A.

Step 5. — Calculate post-silvicultural activity potential suspended sediment discharge (due to streamflow increase).

a. Use worksheet VI.1, columns (1), (5), (6), and (7).

b. Record the total of 8.8 tons/yr on worksheet VI.3, line B.

Note that there is a 24-percent increase in sediment discharge due only to flow increase.

Step 6. — Convert water quality objective from state water quality standards (mg/l) into units compatible with the analysis (tons/yr).

a. Maximum allowable limits as set by state water quality standards for suspended solids is a 30 mg/l increase above existing conditions.

b. Use columns (8) and (9) on worksheet VI.1 to calculate maximum allowable, sediment discharge.

c. Record the total of 38.6 tons/yr on worksheet VI.3, line C.

Bedload Calculation

Step 7. — Establish bedload rating curve.

a. Data points for bedload transport (tons/day) are plotted against stream discharge (cfs), figure VIII.17. Data are shown from worksheet VI.2.

b. log Y = -3.43 + 2.18 log X
   r^2 = 0.99: coefficient of determination

Step 8. — Calculate pre-silvicultural activity bedload discharge.

a. Use columns (1), (2), (3), and (4) on worksheet VI.2.

b. Record the total of 1.4 tons/yr on worksheet VI.3, line E.

Step 9. — Calculate pre-silvicultural activity sediment discharge (suspended and bedload).

a. From step 4, obtain 7.1 tons/yr (suspended sediment) and from step 8, 1.4 tons/yr (bedload sediment) and add for a total of 8.5 tons/yr.

b. Record this total on worksheet VI.3, line K.

Step 10. — Calculate post-silvicultural activity bedload sediment discharge.

a. Use columns (1), (6), (7), and (8) on worksheet VI.2.

b. Record the total of 1.9 tons/yr on worksheet VI.3, line F.

Total Potential Sediment Calculation

Step 11. — Obtain total potential sediment delivered by soil mass movement. Sum the contributions of the coarse size (wksht. VI.3, line D.3) and fine size material (wksht. VI.3, line D.4) to obtain the total soil mass movement contributions which equal 192 tons/yr.

Step 12. — Obtain total potential coarse size sediment delivered by soil mass movement.

a. 24 percent (table IV.1) of delivered soil consists of coarse silts, silt, and clay sizes (only half of the total clay is included in this category) [wksht. IV.1 (soil 2—topsoil)]; thus 76 percent of the delivered soil is coarse material (including the remaining half of the clay, as stable aggregates); therefore, 0.76 × 192 tons = 146 tons/yr of coarse material delivered to streams.

b. Enter this value (146 tons/yr) on worksheet VI.3, lines D.2 and J.1.

c. Median size of coarse portion = 10 mm; record on worksheet VI.3, lines D.3 and J.3.

Step 13. — Determine washload volume delivered from soil mass movement.

a. 24 percent of total delivered volume is washload (tons/yr), therefore,
   total volume soil mass
   movement = 192 tons/yr

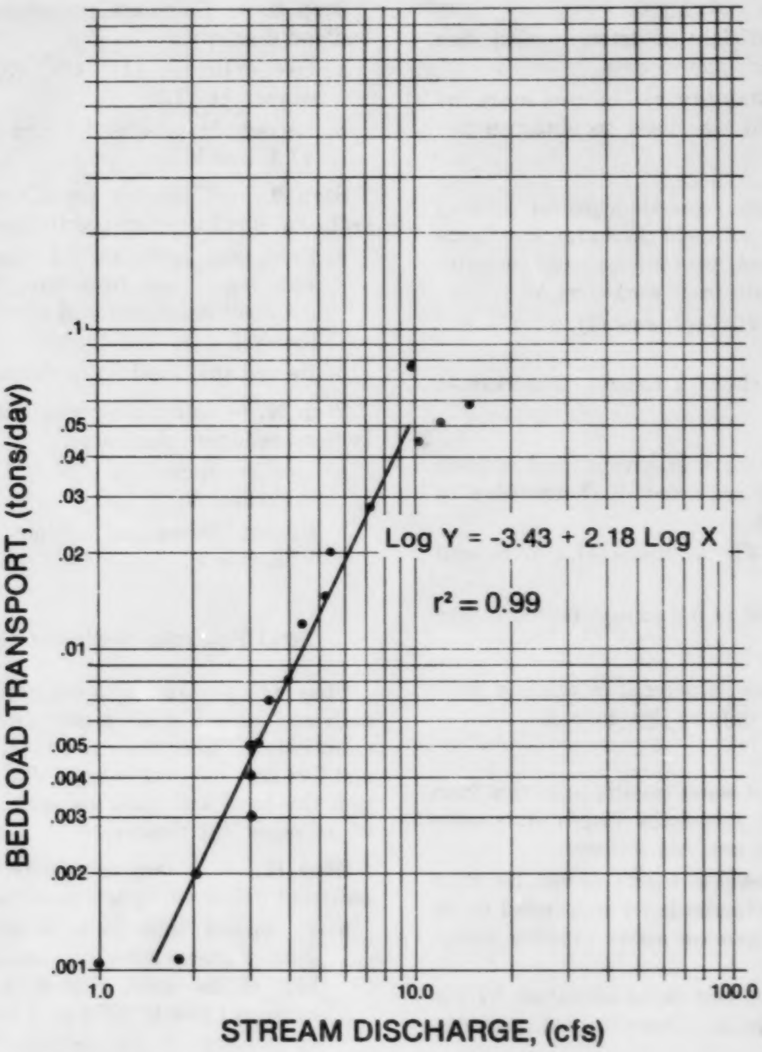

Figure VIII.17.—Bedload rating curve, Horse Creek watershed.

total coarse size soil mass movement = 146 tons/yr
total washload (fine) size = 46 tons/yr

b. Record this total (46 tons/yr) on worksheet VI.3, lines D.4 and J.2.

Step 14. — Determine total delivered tons of suspended sediment from surface erosion.

a. The total of 17.7 tons/yr is obtained from worksheet IV.8.

b. Record this value on worksheet VI.3, line D.1.

Step 15. — Compare total potential post-silvicultural activity suspended sediment (mg/l) to selected limits (tons/yr). On worksheet VI.3:

Add totals of:	tons/yr
Surface erosion (line D.1)	17.7 tons/yr
Total post-silvicultural activity suspended sediment discharge (line B)	8.8 tons/yr
Soil mass movement (washload) (line D.4)	46.0 tons/yr
Total	72.5 tons/yr
Subtract the total pre-silvicultural activity suspended sediment discharge (line A) from the previously determined figure	7.1 tons/yr
The remainder is the total increase in potential suspended sediment discharge (line I.1)	65.4 tons/yr
Subtract the maximum allowable suspended sediment discharge (line C) from the total increase in potential suspended sediment dischrge (line I.1)	38.6 tons/yr
The remainder is the net change (this may be either a positive or negative number) (line I.2)	+26.8 tons/yr

Step 16. — Total potential post-silvicultural activity sediment discharge—all sources.

a. Summation: from steps 5, 10, 11, and 14.

	tons/yr
1. Post-silvicultural activity sediment flow related increases (step 5, wksht. VI.3, line B)	8.8
2. Post-silvicultural activity bedload load, flow related increases (step 10, wksht. VI.3, line F)	1.9
3. Soil mass movement volumes (step 11, wksht. VI.3, line D.2 plus D.4)	192.0
4. Surface erosion source (step 14, wksht. VI.3, line D.1)	17.7
Total	220.4

b. Record on worksheet VI.3, line L.

Step 17. — Increase in total potential sediment discharge resulting from silvicultural activity.

a. Subtract total pre-silvicultural activity sediment discharge (step 9) from total post-silvicultural activity sediment discharge (step 16).

	tons/yr
1. Total post-silvicultural activity (wksht. VI.3, line L)	220.4
2. Total pre-silvicultural activity (wksht. VI.3, line K)	8.5
3. Total potential sediment increase	211.9

b. Record this total increase of 211.9 tons/yr on worksheet VI.3, line M.

Channel Impacts

Step 18. — Channel geometry.

a. Collect channel geometry data for third-order stream being impacted. Record on worksheet VI.5.

1. Water surface slope, measured	0.005 ft/ft
2. Bankful stream width	4.8 ft
3. Bankful stream depth	0.8 ft

b. Channel geometry for the first-order stream being impacted. Record on worksheet VI.5.

1. Water surface slope	0.029 ft/ft
2. Bankful stream width	1.0 ft
3. Bankful stream depth	0.6 ft

Step 19. — Evaluate post-silvicultural activity channel impacts. Determine post-silvicultural activity changes that impact the channel, which would influence stream power calculations by altering water surface slope and/or bankful stream width. The debris-slide on the stream reach being evaluated will change the water surface slope from 0.029 to 0.250 with an increase in bankful width from 1.0 feet to 1.5 feet.

Step 20. — Establish bedload transport rate-stream power relationship for third-order reach or closest adjacent drainageway that has measured data.

Water surface slope = 0.005
(K) Constant = 62.4 lb/ft^3

Use worksheet VI.4 for calculations (see fig. VIII.18).

Step 21. — Make a qualitative determination of channel change potential based on introduced sediment from soil mass movement and channel impacts: Soil mass movement source (coarse size) 146 tons/yr (wksht. VI.3, line J.1). The debris-slide delivery to the first-order stream is instantaneous.

a. To determine channel response on the delivered material, the following calculations are made:

1. Stream power under bankful discharge for first-order reach (wksht. VI.5, line 2A) 1.32 ft/lb/sec
2. Maximum sediment transport under maximum stream power at bankful discharge (fig. VIII. 18) 0.0018 ft/lb/sec

Based on this calculation, the introduced coarse (0.08 tons/day) size (10mm) soil mass movement material of 142 tons exceeds the transport capability of the stream under bankful stream power (0.08 tons/day). Since bankful discharge has a relatively short duration, the 0.08 tons/day transport would be decreased as discharge, and resultant stream power is reduced over time. The expected channel response would be local deposition of sediment (dominant particle size of 10 mm) on the streambed. This would adjust local slope and the width-depth ratio of the channel (based on similar channel response due to debris-slide impacts on similar channels adjacent to Horse Creek).

b. To determine the change in steam power and bankful discharge for Horse Creek at the first-order reach, the following calculations are made:

$$A = (\text{width } 1.0\text{ ft})(\text{depth } 0.6\text{ ft}) = 0.60\text{ ft}^2$$

$$S = 0.029$$

$$\log Q = 0.366 + 1.33 \log 0.60 + 0.05 \log 0.029 - 0.056 (\log 0.029)^2$$

$$Q = 0.73 \text{ cfs (pre-silvicultural activity)}$$

c. Changes in transport rate due to changes in stream power from:

1. Reduced surface water slope
2. Increased width
3. Reduced depth
4. Reduced bankful discharge

Using worksheet VI.5:

Post-silvicultural activity width	1.5 ft
Post-silvicultural activity depth	0.2 ft
Post-silvicultural activity slope	0.0250
Post-silvicultural activity (Q_b) discharge	0.28 cfs
Post-silvicultural activity stream power (ω)	0.29 ft/lb/sec
Post-silvicultural activity bedload transport rate (fig. VIII.18)	2.6×10^{-5} ft/lb/sec

This value (2.6×10^{-5} ft/lb/sec) is converted to tons/day/ft of width by multiplying by 86,400 sec/day and dividing by 2,000 lb/ton .... 0.001 tons/day/ft

This value (0.001 tons/day/ft) is converted to tons/day by multiplying by 1.5 feet (bankful width of stream).

Thus, a reduction in bedload sediment transport from 0.08 tons/day to 0.002 tons/day would indicate an increase in sediment storage in the channel; until such time, recovery would return to pre-silvicultural activity rates. This would reduce the channel stability rating, and by the imbalance in sediment supply—stream energy, disequilibrium conditions would be expected (this is evaluating the coarse fragment portion of soil mass movement sediment supply only).

e. Difference.

Maximum instantaneous, pre-silvicultural activity transport at bankful (Q_{Bpre})	0.08 tons/day
Maximum instantaneous, post-silvicultural activity transport at bankful (Q_{Bpost})	0.002 tons/day
A difference of	0.078 tons/day

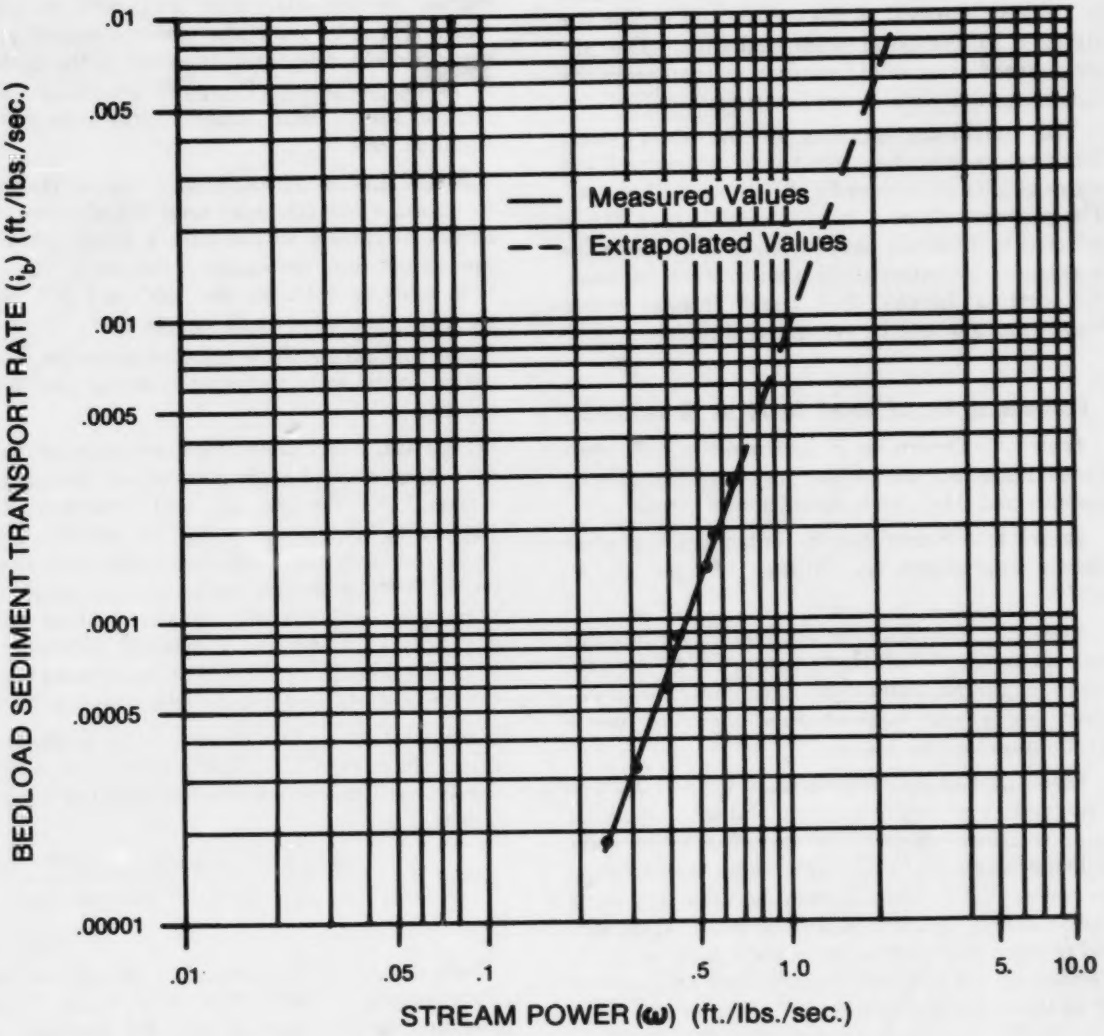

Figure VIII.18.—Bedload transport-stream power relationship, Horse Creek watershed.

TEMPERATURE ANALYSIS

Several of the proposed cutting blocks are close to streams; removal of the trees would expose the streams to increased solar radiation. The additional radiation would result in an increase in the maximum daily water temperature.

The maximum increase in the daily water temperature must be evaluated to determine if the water quality objectives for the stream will be met. The proposed clearcut in hydrographic area 29 was selected to illustrate the procedure to estimate the maximum potential daily temperature increase. All cutting blocks that could impact water temperature would be evaluated similarly.

Computing H, Adjusted Incident Heat Load

Step 1. — Determine H (i.e., incident heat load) based upon latitude of site, critical time of year (month and day), and orientation of stream.

Step 1.1. — Select the solar ephemeris that most closely approaches the latitude of the site, 40 1/2°N.

Step 1.2. — Locate the declination in the solar ephemeris (fig. VII.3) that corresponds to the date when maximum water temperature increase is anticipated: second week in July; therefore, use a declination of +21 1/2°.

Step 1.3. — Once the declination, +21 1/2°, is known, determine the azimuth and solar angle for various times during the day from the solar ephemeris (see fig. VII.6) and record the values in worksheet VII.1. Azimuth readings are found along the outside of the circle and are given for every 10°. Solar angle (i.e., degrees above the horizon) is indicated by the concentric circles and ranges from 0° at the outermost circle to 90° at the center of the circle. The time is indicated above the +23°27′ declination line and is given in hours, solar time.

To determine the solar azimuth and angle that would occur at 12:30 p.m. daylight savings time (DST):

Step 1.3.1. — Follow along the +21 1/2° declination line that is interpolated between the +20° and +23°27′ line. Locate the point that is equal distance between the 11 a.m. (12 noon DST) and noon (1 p.m. DST) time interval. This point represents the 12:30 p.m. DST.

Step 1.3.2. — The solar angle is determined by noting where the point established above (12:30 p.m. with a declination of +21 1/2°) occurs in respect to the solar angle lines present on the figure. The solar angle lines are represented as concentric circles and range from 90° at the center to 0° at the periphery. The point established above falls on the 70° line; therefore, the solar angle is equal to 70°.

Step 1.3.3. — The solar azimuth is determined by noting where the point established in step 1.3.1 occurs in respect to the solar azimuth lines that radiate out from the center of the circle. The point falls midway between the 150° and 160° lines; therefore, the solar angle equals 155°.

More points should be selected about the midday period, when solar radiation is at the greatest intensity.

Step 1.4. — Evaluate the orientation of the sun (i.e., azimuth and angle determined from step 1.3 above) with the stream, and determine what vegetation effectively shades the stream. To do this, compare stream effective width with shadow length. Determine the maximum solar angle (i.e., maximum radiation influx to stream) that will occur when the stream is exposed following the silvicultural activity. Height of the existing vegetation immediately adjacent to the stream is 70 feet.

Step 1.4.1. — The direction the shadows fall across the stream will determine effective width of the stream. Effective width is computed using the following formula:

$$\text{EW} = \frac{\text{measured average stream width}}{\text{sine}\,|\,\text{azimuth stream - azimuth sun}\,|} \qquad \text{(VII.4)}$$

The azimuth of the particular stream used for this example is 225°. Effective width varies depending on the time of day. For example, at 12:30 (wksht. VII.1) EW would be equal to:

$$\text{EW} = \frac{1.5 \text{ ft}}{\text{sine}\,|\,225° - 155°\,|} = 1.6 \text{ ft}$$

The absolute value of the azimuth of the stream subtracted from the azimuth of the sun must be less than a 90° angle. Should the difference exceed 90°, subtract this absolute value from 180° to obtain the correct acute angle. The sine is then taken of this computed acute angle.

Step 1.4.2. — Shadow length is computed using the formula:

$$S = \frac{\text{height vegetation}}{\text{tangent solar angle}} \qquad \text{(VII.5)}$$

For example, at 12:30, S would be equal to:

$$S = 70 \text{ ft/tangent } 70° = 25.5 \text{ ft}$$

Note, the **only** periods of the day that should be considered are those when existing vegetation that will be eliminated by the silvicultural activity effectively shades the stream (i.e., when the shadow length extends onto some portion of the stream). Those periods of the day when the stream is not effectively shaded by the existing vegetation will not have an increase in net radiation if the vegetation is removed by the silvicultural activity. Also, there may be periods of the day when the stream is effectively shaded by existing vegetation that will **not** be removed by the silvicultural activity; therefore, the proposed silvicultural activity will have no impact on water temperature.

Summary of steps 1.4.1 and 1.4.2: The existing trees that are scheduled to be cut provide shade to the stream. The only time when the trees do not shade the stream is about 2:10 p.m., when the stream's effective width is infinity (sun is oriented with the stream) and the shadow length is only 28.1 feet. Therefore, removal of this vegetation would result in exposure of the water surface to increased solar radiation.

The proposed silvicultural activity would have the maximum impact on water temperature at 1 p.m. (solar noon) when the solar angle and radiation are greatest.

Step 1.5. — Topographic shading should be evaluated to determine if the water course would be shaded by topographic features. For topographic shading, the percent slope of the ground must exceed the percent slope of the solar angle (i.e., tangent of the solar angle). In the present example, the

side slope = 30%
solar angle = 72° or 308%

Thus, topographic shading is not possible due to the angle of the sun and relatively gentle topographic relief.

Step 1.6. — Calculate the incident heat load for the site. This is obtained from reading the values shown in figure VII.7. To read these values, apply the following:

1. Select the correct curve (shown in fig. VII.7) obtained from the correct solar ephemeris (fig. VII.3): in this example, 40°N latitude, given a declination of +21 1/2°: 72°. (Note that the midday value will always have an orientation, i.e., azimuth, of due south.)
2. In figure VII.8, interpolate between the 70° and 80° curve to obtain the 72° values.
3. Determine the critical time period, which in step 1.4 was found to be 1 p.m.
4. Find the average H value. In this example, the travel time through the reach is only 0.3 hours, so it is not necessary to find an average H value. From figure VII.8, with a 72° midday angle, the H value for 1 p.m. is approximately 4.7 BTU/ft²−min. (Note: If the solar ephemeris had been used for 45°N latitude, the H value would have be approximately 4.8 BTU/ft²−min. If the solar ephemeris had been used for 35°N latitude, the H value would have been 4.5 BTU/ft²−min). Figure VII.8 illustrates the procedure used to obtain H.

Step 1.7. — Because bedrock acts as a heat sink, reducing the heat load absorbed by the water, the H value must be corrected to reflect this heat loss.

$$H_{\text{adjusted}} = WH + [B\,(1.00 - C)\,H] \qquad \text{(VII.6)}$$

where for Horse Creek:

W = percent streambed without bedrock = 10%
H = unadjusted heat load = 4.7 BTU/ft²−min with a solar ephemeris for 40°N latitude (step 3.6)
B = percent streambed with rock = 90%
C = correction factor = 18% (see explanation for C directly below)

(Note: All percent values used in eq. III.6 are in decimal form.)

Now, C is obtained from figure VII.9. In the example, bedrock comprises 90 percent of the streambed; therefore, H should be reduced by 18 percent.

Thus,

$$\begin{aligned} H_{\text{adjusted}} &= [0.1 \times 4.7] \\ &\quad + [0.9 \times (1.00 - 0.18) \times 4.7] \\ &= 3.94 \text{ BTU/ft}^2\text{−min} \end{aligned}$$

Computing Q, Stream Discharge

Step 2. — Determine stream discharge following the proposed silvicultural activity during the critical summer low-flow period when maximum temeratures are anticipated. A pre-activity baseflow measurement during the critical summer period was taken. Discharge during the critical period was 0.4 cfs.

Computing A, Adjusted Surface Area

Step 3. — Determine the adjusted surface area of **flowing water** exposed by the proposed silvicultural activity.

Step 3.1. — Total surface area of **flowing water**

$$A_{total} = LW \qquad \text{(VII.7a)}$$

where:

L = length of exposed reach

W = width of flowing water

$A_{total} = 530 \text{ ft} \times 1.5 \text{ ft}$

$= 795 \text{ ft}^2$

Step 3.2. — Total surface area shaded by brush

$$A_{shade\ brush} = LW(\%\text{ stream shaded by brush only}) \qquad \text{(VII.7b)}$$

$$= 530 \text{ ft} \times 1.5 \text{ ft} \times 0.15$$

$$= 120 \text{ ft}^2$$

Step 3.3. — Surface area exposed under current vegetative canopy cover; correct for transmission of light through the existing stand that has a 65 percent crown closure. Since only vertical crown closure values are available, estimate the percentage transmission of solar radiation through the overstory canopy. Values for these estimates may be obtained from figure VII.D.1. A crown closure of 65 percent permits about 8 percent transmission of solar radiation.

$$A_{presently\ exposed} = (A_{total} - A_{shade\ brush}) \times \%\text{ transmission through existing vegetation} \qquad \text{(VII.7c)}$$

$$= (795 \text{ ft}^2 - 120 \text{ ft}^2 \times 0.08)$$

$$= 54 \text{ ft}^2$$

Step 3.4. — The adjusted surface area that will be exposed to increased solar radiation if all vegetation is removed is

$$A_{adjusted} = A_{total} - A_{presently\ exposed} \qquad \text{(VII.7d)}$$

$$= 795 \text{ ft}^2 - 54 \text{ ft}^2$$

$$= 741 \text{ ft}^2$$

Step 4. — Estimate ΔT, maximum potential daily temperature increase in °F if the proposed silvicultural activity is implemented. Solve equation VII.3a

$$\Delta T = \frac{A_{adjusted} H_{adjusted}}{Q} \times 0.000267 \qquad \text{(VII.3a)}$$

$A = 741 \text{ ft}^2$

$H = 3.94 \text{ BTU/ft}^2\text{-min}$

$Q = 0.4 \text{ cfs}$

$$\Delta T = \frac{(741 \text{ ft}^2)\ (3.94 \text{ BTU/ft}^2 - \text{min})}{0.4 \text{ cfs}} \times 0.000267$$

$$= 1.9\ °\text{F}$$

The Mixing Ratio Formula

The following example is provided to illustrate the use of the mixing ratio formula for evaluating downstream water temperature impacts. The water temperature increase associated with the proposed clearcut in hydrographic area 29 has previously been evaluated, and a maximum potential daily temperature increase of 1.9°F was estimated. With similar evaluations made for proposed clearcuts in hydrographic areas 27 and 28, an estimate of the water temperature of the main stream draining this area can now be obtained.

The data and results of the individual water temperature evaluations are recorded on worksheet VII.2. The pre-silvicultural activity stream water temperature is 55°F. The sequence of steps to obtain an estimate of the water temperature of the main stream draining this area follows.

Hydrographic area 27 stream reach. — The estimated maximum potential daily stream temperature increase (2.5°F) is added to the pre-silvicultural activity stream temperature (55°F) to obtain an estimate of the water temperature (57.5°F) below the proposed clearcut draining this hydrographic area.

Hydrographic area 28 stream reach. — The estimated maximum potential daily stream temperature increase (2.1°F) is added to the pre-silvicultural activity stream temperature (55°F) to obtain an estimate of the water temperature (57.1°F) below the proposed clearcut draining this hydrographic area.

To estimate the water temperature below the confluence of the streams draining hydrographic areas 27 and 28, the mixing ratio formula may be used.

$$T_D = \frac{D_M T_M + D_T T_T}{D_M + D_T} \qquad \text{(VII.8)}$$

where:

T_D = temperature downstream after the tributary (hydrographic area 28) enters the main stream (hydrographic area 27)

D_M = discharge main stream = 0.4 cfs

T_M = temperature main stream above tributary = 57.5°F

D_T = discharge stream draining treated area = 0.3 cfs

T_T = temperature stream below treated area equals temperature above plus computed temperature increase (i.e., Brown's model) or

$T_T = T_A + \Delta T = 55°F + 2.1°F$
$= 57.1°F$

T_A = temperature stream above treated area = 55°F

ΔT = temperature increase computed using Brown's model = 2.1°F

Therefore,

$$T_D = \frac{(0.4\text{ cfs})\,(57.5°F) + (0.3\text{ cfs})(57.1°F)}{(0.4\text{ cfs}) + (0.3\text{ cfs})}$$

$$= 57.3°F$$

The main stream below the confluence will have a water temperature of 57.3°F.

Hydrographic area 29 stream reach. — The estimated maximum potential daily stream temperture increase (1.9°F) is added to the pre-silvicultural activity stream temperature (55°F) to obtain an estimate of the water temperature (56.9°F) below the proposed clearcut draining this hydrographic area.

To estimate the water temperture below the confluence of the main stream and the stream draining hydrographic area 29, the mixing ratio formula may be used.

$$T_D = \frac{D_M T_M + D_T T_T}{D_M + D_T} \qquad \text{(VII.8)}$$

where,

T_D = temperature downstream after the tributary (hydrographic area 29) enters the main stream

D_M = discharge main stream = 0.7 cfs

T_M = temperature main stream above tributary = 57.3°F

D_T = discharge stream draining treated area = 0.4 cfs

T_T = temperature stream below treated area equals temperature above plus computed temperature increase (i.e., Brown's model)

$T_T = T_A + \Delta T = 55°F + 1.9°F$
$= 56.9°F$

T_A = temperature stream above treated area = 55°F

ΔT = temperature increase computed using Brown's model = 1.9°F

Therefore,

$$T_D = \frac{(0.7\text{ cfs})\,(57.3°F) + (0.4\text{ cfs})\,(56.9°F)}{(0.7\text{ cfs}) + (0.4\text{ cfs})}$$

$$= 57.2°F$$

The main stream below the confluence will have a water temperature of 57.2°F or a maximum daily temperature increase of 2.2°F. This same procedure is used to evaluate other tributary streams further downstream.

Groundwater influence has previously been demonstrated in the Grits Creek example.

ANALYSIS REVIEW

Interpretation Of The Analysis Outputs

The proposed silvicultural plan has been evaluated in the preceding discussion and estimated values from various outputs are shown in table VIII.5. These outputs are compared to previously determined water quality objectives. When considering whether these objectives have been met or not, it is important to consider the reliability of the computed values as previously discussed in the analysis review for Grits Creek. A review of the data reliability and the computed outputs for Horse Creek indicates the possibility that the water quality objectives will not be met; therefore, a revised silvicultural plan that includes a different mix of controls should be prepared and evaluated.

Comparing Analysis Outputs To Water Quality Objectives

Two potential non-point source pollutants must be controlled—total potential sediment and water temperature. Evaluation of the individual components of the estimated total potential sediment value (216 tons), clearly indicates the major contribution of potential sediment is from soil mass movement (192 tons). The surface erosion (17.7 tons) and increased flow (6.3 tons) contributions, although significant, are an order of magnitude less than the soil mass movement. Therefore, first priority is to evaluate control opportunities for minimizing the soil mass movement non-point source. The second priority is to consider control opportunities for the surface erosion component.

The sediment contribution from increased streamflows cannot be significantly altered without major reductions in amount of area harvested or changes in the cutting pattern. Since the proposed silvicultural plan has an optimum layout of cutting units, and their contribution to increased flow was small, no further consideration of flow-related controls is necessary.

Since existing stream temperatures (55°F) are suitable for the fishery resource and the area is undisturbed, mitigative controls before the activity are unnecessary; only preventive controls need be considered.

Following is a discussion of the procedures applied to select a different mix of controls that could be implemented to meet the water quality objectives—first for total potential sediment and then for temperature. These procedures are discussed in chapter II, appendix A, "Example Three: Selecting Controls When Plans Do Not Meet Water Quality Objectives." After identifying control opportunities, the favorable and adverse impacts of the controls, along with possible interactions, are evaluated before finally selecting control opportunities to be used.

Control Opportunities For Soil Mass Movement

Since it is very difficult to apply effective mitigative controls after a large soil mass movement occurs, only preventive control opportunities will be evaluated. Table II.2 of "Chapter II: Control Opportunities" presents the potential resource impacts and control opportunities.

Soil mass movement initiation or acceleration in the Horse Creek watershed may be caused by road construction, due to large fill sections, and loss of root strength, due to vegetative removal. Based upon this assessment of the causes of soil mass movement, controls for slope configuration changes and vegetative changes are reviewed in table II.2, and preventive controls are identified.

Once the possible preventive control opportunities have been identified, table II.3 is used to determine which variables that influence soil mass movement are affected by the various control opportunities. That portion of table II.3 dealing with slope configuration and vegetative change is examined. From the possible control opportunities for slope configuration change, it is apparent that some controls influence several variables and would, therefore, be more effective in controlling soil mass movement than controls that influence only one. The following preventive control opportunities affect the principal variables influencing soil mass movement:

1. Bench cut and compact fill
2. Full bench section
3. Reduce logging road density
4. Road and landing location
5. Slope rounding or reduction in slope cut

Possible preventive controls for vegetative change are:

1. Cutting block design
2. Maintain ground cover

From this list of possible control opportunities, the proposed silvicultural activity was modified for soil mass movement by:

a. Elimination of cutting block 14 on the unstable area. The volume of timber not removed in this unit has been obtained elsewhere by making slight changes to enlarge other cutting units on stable terrain.
b. Removal of the road and landings in hydrographic areas 26 and 27 that served cutting block 14.

By incorporating these controls, the soil mass movement hazard index will be reduced from high to moderate. Worksheet V.2 is completed based upon the above preventive controls. The new silvicultural activity factor total is 7. Combining this with the natural total of 31 gives the new total value for the modified silvicultural activity of 38, which falls within the medium hazard range (21-44) for soil mass movement.

Control Opportunities For Surface Erosion

By reviewing worksheet IV.8, the maps (figs. IV.14 to IV.18), and using professional judgment, the following resource impacts and conditions were noted:

Problem No. 1:	Some landings were located close to a stream, allowing direct delivery of eroded material.
Problem No. 2:	Because there was no road surfacing included in the proposed silvicultural plan, erosion resulted from bare road surface.

Control opportunities for Problem No. 1, road and landing location, are discussed under resource impacts for soil compaction, bare soil, excess water, and water concentration. Bare soil and compaction are directly related to the number of landings and miles of road in the proposed silvicultural activity area. Since the initial plan has incorporated the minimum number of landings and miles of roads, controls listed here are not as applicable as controls for excess water and water concentration. Using sections B and C of the "Control Opportunities" chapter, the following applicable controls were selected:

Excess water

1. Cutting block design
2. Waterside area
3. Revegetate treated areas

Water concentration

1. Reduce road grades
2. Road and landing location
3. Waterside areas

The cutting block designs have been carefully chosen, and there is little opportunity to make significant changes. The proposed silvicultural plan already contains provisions for revegetating treated areas. The remaining control, waterside areas, is discussed below.

Under "water concentration," the control opportunity "reduce road grades" is not practical, since the road locations are determined by minimum grades to reach benches and suitable cutting blocks. Considering the control opportunity "road and landing location," it was determined that there were opportunities to make some slight modifications in landing locations by moving them back from stream channels. At the same time, the control opportunity "waterside areas" (leaving some area to act as a sediment filter strip) was also utilized to reduce the amount of sediment delivered to a channel.

Using the same calculation procedures outlined in chapter IV and in the example for the proposed silvicultural plan, a new analysis was made using revised values for the different landing locations (wkshts. IV.2 to IV.4 and IV.6 to IV.8).

By moving a landing a short distance away from a stream channel, three factors affecting sediment delivery are changed (compare wksht. IV.7 for both plans—proposed and revised). First, the distance from the edge of the disturbance to the stream channel is increased, creating more area for sediment deposition; second, the amount of ground cover between the disturbance and channel increases; third, the surface roughness increases slightly. The net result is a change in the sediment delivery index from 0.11 under proposed management, to 0.01 in the modified plan. This would reduce the amount of eroded material that might be delivered to a stream by 91 percent for each landing next to a stream. The total from all landings has been reduced from 0.9 tons/yr to 0.03 tons/yr (wksht. IV.8 for both plans).

Control opportunities for Problem No. 2, "no road surfacing," are found in section B under bare soil, with "protection of road bare surface areas with non-living material" being the most practical. A decision was made to use 6 inches of crushed gravel on all roadbeds. The same procedures outlined under roads should be applied to the proposed silvicultural plan, except that the VM factor has now been changed for the running surface from 1.24 (wksht. IV.6, proposed) to 0.005 (wksht. IV.6, revised). The weighted VM factor for the road is now 0.17, which compares with a value of 0.91 for the proposed plan. A summary on worksheets IV.8 (for both plans) shows that the total for all roads has now been reduced from 8.1 tons/yr to 1.3 tons/yr, or an 84 percent reduction.

Control Opportunities For Temperature

To meet the temperature water quality objective, the maximum potential daily temperature increase must be reduced by applying preventive controls. Table II.2 of "Chapter II: Control Opportunities" presents potential resource impacts and control opportunities to be evaluated. Water temperature increases resulting from silvicultural activities are caused by removal of vegetation that shades the stream. Therefore, controls for stream shading are reviewed in table II.2.

Three preventive control opportunities are presented that could be used to meet the water quality objectives:

1. Cutting block design
2. Directional felling
3. Waterside area

Directional felling away from the stream is already specified in the proposed silvicultural plan and so is not an alternative. Both cutting block design and waterside areas are viable control opportunities.

Cutting block design. — Using the basic procedure presented in "Chapter VII: Temperature," compute the maximum length of stream channel that could be exposed with a resultant maximum potential daily temperature increase of 1.5°F.

From the previous evaluations: The stream reach length that would be exposed if the proposed silvicultural activity was implemented was 530 feet. Maximum potential daily temperature increase would be 1.9°F. The water quality objective limits the maximum potential daily temperature increase to 1.5°F (temperature objective). A direct relationship can be established to estimate the reach of stream that could be exposed (length objective).

$$\frac{\Delta T}{T_{obj}} = \frac{L}{L_{obj}}$$

where:

ΔT = potential daily temperature increase
T_{obj} = allowable daily temperature increase
L = potential exposed stream length
L_{obj} = allowable exposed stream length

$$L_{obj} = \frac{1.5°F}{1.9°F} \times 530\text{ ft} = 418\text{ ft}$$

By modifying the proposed cutting block design so that no more than 418 feet of the stream is exposed, the water quality objective will be met.

Waterside areas. — Using the basic procedure presented in "Chapter VII: Temperature," compute the minimum crown closure that is required to prevent a maximum potential daily temperature increase greater than 1.5°F.

From the previous evaluation:

$$A_{total} = 795\text{ ft}^2$$
$$A_{shade\ brush} = 120\text{ ft}^2$$
$$H_{adjusted} = 3.94\text{ BTU/ft}^2\text{–min}$$
$$Q = 0.4\text{ cfs}$$

Estimate the maximum $A_{adjusted}$ value that would result in a ΔT value of 1.5°F, water quality objective.

$$\Delta T = \frac{(A_{adjusted})(H_{adjusted})}{Q} \times 0.000267$$

$$1.5°F = \frac{(A_{adjusted})\,(3.94\text{ BTU/ft}^2\text{–min})}{0.4\text{ cfs}} \times 0.000267$$

Rearranging the equation gives:

$$A_{adjusted} = \frac{(1.5°F)\,(0.4\text{ cfs})}{(3.94\text{ BTU/ft}^2\text{–min})\,(0.000267)} = 570\text{ ft}^2$$

$$A_{adjusted} = A_{total} - A_{presently\ exposed}$$

Rearranging the equation gives:

$$A_{presently\ exposed} = A_{total} - A_{adjusted}$$
$$= 795\text{ft}^2 - 570\text{ ft}^2 = 225\text{ ft}^2$$

$A_{presently\ exposed} = (A_{total} - A_{shade\ brush}) \times$ percent transmission through existing vegetation

Rearranging the equation gives:

$$\text{percent transmission through existing vegetation} = A_{presently\ exposed} / (A_{total} - A_{shade\ brush})$$

$$= \frac{225\text{ ft}^2}{795\text{ ft}^2 - 120\text{ ft}^2} = 0.34$$

From figure VII.D.1, 34 percent transmission corresponds to a crown close of 35 percent. A reduction in the amount of vegetation removed from the streamside zone so that 35 percent crown closure existed after the silvicultural activity would meet the water quality objectives for temperature.

The forest manager, after reviewing both viable control opportunities and discussing the alternatives with other resource specialists, selected the waterside area control. Using this control, only mature overstory trees were removed, leaving a productive understory for other uses.

Table VIII.6

Summary of quantitative outputs for: Revised Plan, Horse Creek

Chapter	Line No.	Output description		Computed value		Chapter reference (worksheets)
				Pre-activity	Post-activity	
Hydrology: Chapter III	1	Water available for annual streamflow		15.4 in	18.1 in	III.5, III.6
	2	Increase in water available for annual streamflow			2.7 in	III.5, III.6
	3	Peak discharge		10.2 cfs	10.99 cfs	III.7, III.8
	4	Date of peak discharge		June 15	June 1	III.7, III.8
	5	Hydrograph				III.7, III.8
	6	7-day flow duration curve		N.A.	N.A.	
Surface Erosion: Chapter IV	7	Surface soil loss		N.A.	490 tons/yr	IV.3
	8	Sediment delivered to stream channel		N.A.	9.8 tons/yr	IV.8
Soil Mass Movement: Chapter V	9	Hazard index		31	38	V.2
	10	Weight of sediment	Coarse >0.062 mm	N.A.	N.A.	
	11		Fine <0.062 mm	N.A.	N.A.	
	12		Total	N.A.	0.0 tons/yr	V.6
	13	Acceleration factor			3	V.6
Total Potential Sediment: Chapter VI	14	Sediment discharge due to flow change	Bedload	1.4 tons/yr	1.9 tons/yr	VI.3 line E VI.3 line F
	15		Suspended	7.1 tons/yr	8.8 tons/yr	VI.3 line A VI.3 line B
	16		Total	8.5 tons/yr	10.7 tons/yr	VI.3 line K VI.3 line G
	17	Total suspended sediment discharge from all sources		7.1 tons/yr	18.6 tons/yr	VI.3 line A line I.1 + A
	18	Increase in total potential bedload plus suspended sediment from all sources			12.0 tons/yr	VI.3 line M
Temperature: Chapter VII	19	Potential temperature changes			1.5°F	VII.2

Revised Silvicultural Plan

Based on these possible control opportunities, a revised silvicultural plan was prepared that consisted of the following changes:

1. Leave vegetation on the unstable area in hydrographic area 26, eliminating cutting block CC14.
2. Increase slightly all other cutting units to accommodate loss of timber from cutting block CC14.
3. Eliminate road and landings to serve cutting block CC14.
4. Move some landings further away from streams.
5. Use 6 inches of crushed rock on all road surfaces.
6. Use waterside areas with a crown closure of 35 percent to shade streams.

The summary of computed outputs for the revised silvicultural plan with these controls is shown on table VIII.6.

The next step is to assess the possible adverse impacts of these controls. With the removal of more timber on other cutting units, it is expected that the surface erosion figures would increase; however, the changes were insignificant on all but hydrographic areas 14 and 16. These two areas show an increase of 0.2 tons/yr of delivered sediment (wksht. IV.8 for both proposed and revised plans).

For this hypothetical example, the net effect of these controls has been a reduction in all non-point source pollutant outputs (table VIII.6). The soil mass movement hazard index was reduced from 61 to 39. The anticipated impacts of the introduced material on the first-order drainage has been eliminated. The delivered sediment from surface erosion sources has been reduced from 17.7 to 9.8 tons/yr. The transport efficiency of the stream channel will be maintained and is capable of handling the available sediment without major channel adjustments and stability change. Considering the water quality objectives, limiting suspended sediment discharge to 38.6 tons/yr and allowing a maximum water temperature increase of 1.5°F, the revised silvicultural plan is determined to be acceptable from a water quality standpoint.

Worksheets for Horse Creek, proposed and revised plans

Worksheets are presented in numerical order with all III.1-III.4 proposed followed by III.1-III.4 revised, IV.1-IV.8 proposed followed by IV.1-IV.8 revised, etc.

WORKSHEET

Water available for streamflow for the

(1) Watershed name Horse Creek

(2) Hydrologic region 4

(5) Vegetation type Lodgepole pine

(6) Annual precipitation 34.3 inches

Season name/dates (9)	Silvicultural prescription		Area		Precipitation (in) (14)	Snow retention coef. (15)	Adjusted snow retention coef. (16)	Adjusted precipitation (in) (17)
	Compartment (10)	Silvicultural state (11)	Acres (12)	% (13)				
WINTER 10/1 - 2/28	Unimpacted	Forested	600	1.000	16.1	1.0	1.0	16.1
	Impacted							
	Total for season		600	1.000	16.1			
SPRING 3/1 - 6/30	Unimpacted	Forested	600	1.000	12.1	1.0	1.0	12.1
	Impacted							
	Total for season		600	1.000	12.1			
SUMMER and FALL 7/1 - 9/30	Unimpacted	Forested	600	1.000	6.1	1.0	1.0	6.1
	Impacted							
	Total for season		600	1.000	6.1			
	Unimpacted							
	Impacted							
	Total for season							

Water available for annual streamflow (in)	Unimpacted	Forested	(30)
			(31)
	Impacted		(32)
			(33)
			(34)
			(35)

III.5

existing condition in snow dominated regions

(3) Total watershed area (acres) 600 (4) Dominant energy-aspect Southwest

(7) Windward length of open area (tree heights) 0 (8) Tree height (feet) 70

ET (in) (18)	Basal area (ft^2/ac) (19)	Cover density		ET modifier coef. (22)	Adjusted ET (in) (23)	Water available for streamflow (in)					
		% (20)	%C_{dmax} (21)			(24)	(25)	(26)	(27)	(28)	(29)
2.1	200	33	100	1.0	2.1	14.0					
7.6	200	33	100	1.0	7.6	4.5					
9.2	200	33	100	1.0	9.2	-3.1					
						15.4					

Notes for Worksheet III.5

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in the text.
(3)-(8)	User supplied.
(9)	Seasons for each hydrologic region are described in the text.
(10)	The unimpacted compartment includes areas not affected by silvicultural activity. The impacted compartment includes areas affected by silvicultural activity. Impacted areas do not have to be physically disturbed by the silvicultural activity. For example, if an area is subject to snow redistribution due to a silvicultural activity, it is an impacted area.
(11)	Areas of similar hydrologic response as identified and delineated by vegetation or silvicultural activity.
(12)	User supplied.
(13)	Column (12) ÷ Item (3).
(14)	User supplied.
(15)	From figure III.6 or appendix A or user supplied.
(16)	Snow retention coefficient adjustment for open areas:

$$\rho_{oadj} = 1 + (\rho_o - 1)\left(\frac{.50}{X}\right)$$

where:

ρ_{oadj} = adjusted snow retention coefficient for open areas (receiving areas)

ρ_o = snow retention coefficient for open areas

$X = \dfrac{\text{open area (in acres)}}{\text{impacted area (in acres)}}$

Snow retention coefficient adjustment for forested source areas (impacted forest areas):

$$\rho_f = \frac{1-\rho_{oadj}\,X}{1-X}$$

where:

ρ_f = adjusted snow retention coefficient for areas affected by snow redistribution (source areas)

$$X = \frac{\text{open area (in acres)}}{\text{impacted area (in acres)}}$$

(17) Column (14) x column (16)

(18) From figures III.24 to III.40 or user supplied.

(19) User supplied (not required if % cover density is user supplied).

(20) From figures III.41 to III.45 or user supplied.

(21) (Column (20) ÷ C_{dmax}) x 100 where C_{dmax} is the % cover density required for complete hydrologic utilization. C_{dmax} is determined by professional judgment at the site.

(22) From figures III.46 to III.56.

(23) Column (18) x column (22).

(24)-(29) The quanitity [column (17)-column (23)] x column (13).

(30) Sum of column (24).

(31) Sum of column (25).

(32) Sum of column (26).

(33) Sum of column (27).

(34) Sum of column (28).

(35) Sum of column (29).

WORKSHEET

Water available for streamflow for the

(1) Watershed name Horse Creek
(2) Hydrologic region 4
(5) Vegetation type Lodgepole Pine
(6) Annual precipitation 34.3 inches

Season name/dates (9)	Silvicultural prescription		Area		Precipitation (in) (14)	Snow retention coef. (15)	Adjusted snow retention coef. (16)	Adjusted precipitation (in) (17)
	Compartment (10)	Silvicultural state (11)	Acres (12)	% (13)				
WINTER 10/1 - 2/28	Unimpacted	Forested	135.0	.225	16.1	1.00	1.00	16.1
	Impacted	Forested	153.5	.256	16.1	—	.55	8.9
		Clearcut	311.5	.519	16.1	1.3	1.22	19.6
	Total for season		600.0	1.000	16.1			
SPRING 3/1 - 6/30	Unimpacted	Forested	135.0	.225	12.1	1.00	1.00	12.1
	Impacted	Forested	153.5	.256	12.1	—	.55	6.7
		Clearcut	311.5	.519	12.1	1.3	1.22	14.8
	Total for season		600.0	1.000	12.1			
SUMMER and FALL 7/1 - 9/30	Unimpacted	Forested	135.0	.225	6.1	1.0	1.0	6.1
	Impacted	Forested	153.5	.256	6.1	1.0	1.0	6.1
		Clearcut	311.5	.519	6.1	1.0	1.0	6.1
	Total for season		600.0	1.000	6.1			
	Unimpacted							
	Impacted							
	Total for season							

Water available for annual streamflow (in)	Unimpacted	Forested	(30)
			(31)
	Impacted	Forested	(32)
		Clearcut	(33)
			(34)
			(35)

III.6

proposed condition in snow dominated regions

(3) Total watershed area (acres) 600 (4) Dominant energy-aspect Southwest

(7) Windward length of open area (tree heights) 6 (8) Tree height (feet) 70

ET (in) (18)	Basal area (ft^2/ac) (19)	Cover density		ET modifier coef. (22)	Adjusted ET (in) (23)	Water available for streamflow (in)					
		% (20)	%C_{dmax} (21)			(24)	(25)	(26)	(27)	(28)	(29)
2.1	200	33	100	1.00	2.1	3.2					
2.1	200	33	100	1.00	2.1			1.7			
2.1	0	0	0	.60	1.3				9.5		

7.6	200	33	100	1.00	7.6	1.0					
6.1	200	33	100	1.00	6.1			0.2			
7.6	0	0	0	1.07	8.1				3.5		

9.2	200	33	100	1.00	9.2	-0.7					
9.2	200	33	100	1.00	9.2			-0.8			
9.2	0	0	0	.55	5.1				0.5		

3.5					
		1.1			
			13.5		

Notes for Worksheet III.6

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in the text.
(3)-(8)	User supplied.
(9)	Seasons for each hydrologic region are described in the text.
(10)	The unimpacted compartment includes areas not affected by silvicultural activity. The impacted compartment includes areas affected by silvicultural activity. Impacted areas do not have to be physically disturbed by the silvicultural activity. For example, if an area is subject to snow redistribution due to a silvicultural activity, it is an impacted area.
(11)	Areas of similar hydrologic response as identified and delineated by vegetation or silvicultural activity.
(12)	User supplied.
(13)	Column (12) ÷ item (3).
(14)	User supplied.
(15)	From figure III.6 or appendix A or user supplied.
(16)	Snow retention coefficient adjustment for open areas: $\rho_{oadj} = 1 + (\rho_o - 1)(\frac{.50}{X})$

where:

ρ_{oadj} = adjusted snow retention coefficient for open areas (receiving areas)

ρ_o = snow retention coefficient for open areas

$X = \frac{\text{open area (in acres)}}{\text{impacted area (in acres)}}$

Snow retention coefficient adjustment for forested source areas (impacted forest areas):

$$\rho_f = \frac{1 - \rho_{oadj}\, X}{1 - X}$$

where:

ρ_f = adjusted snow retention coefficient for areas affected by snow redistribution (source areas)

$$X = \frac{\text{open area (in acres)}}{\text{impacted area (in acres)}}$$

(17) Column (14) x column (16)

(18) From figures III.24 to III.40 or user supplied.

(19) User supplied (not required if % cover density is user supplied).

(20) From figures III.41 to III.45 or user supplied.

(21) (Column (20) ÷ C_{dmax}) x 100 where C_{dmax} is the % cover density required for complete hydrologic utilization. C_{dmax} is determined by professional judgment at the site.

(22) From figures III.46 to III.56.

(23) Column (18) x column (22).

(24)-(29) The quanitity [column (17)-column (23)] x column (13).

(30) Sum of column (24).

(31) Sum of column (25).

(32) Sum of column (26).

(33) Sum of column (27).

(34) Sum of column (28).

(35) Sum of column (29).

WORKSHEET

Existing condition hydrograph

(1) Watershed name Horse Creek

Date or interval (3)	Distribution of water								
	Unimpacted						Impacted		
	Forested								
	% (4)	inches (5)	cfs (6)	% (7)	inches (8)	cfs (9)	% (10)	inches (11)	cfs (12)
APRIL 8	.0000	.00	.00						
14	.0000	.00	.00						
20	.0000	.00	.00						
26	.0000	.00	.00						
MAY 2	.0050	.08	.34						
8	.0150	.23	.97						
14	.0250	.39	1.64						
20	.0400	.62	2.61						
26	.0600	.92	3.87						
JUNE 1	.0825	1.27	5.35						
7	.1050	1.62	6.82						
13	.1400	2.16	9.09						
19	.1575	2.43	10.23						
25	.1400	2.16	9.09						
JULY 1	.1050	1.62	6.82						
7	.0650	1.00	4.21						
13	.0375	.58	2.44						
19	.0175	.27	1.14						
25	.0050	.08	.34						
31	.0000	.00	.00						

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in text.
(3)	Supplied by user. Either date snowmelt begins or date of peak snowmelt runoff.
(4),(7), (10),(13), (16),(19)	Digitized excess water distribution (%) from tables III.11 to III.22 for forested and open condition. Interpolate between forested and open for other conditions.

III.7

for snow dominated regions

(2) Hydrologic region 4

available for annual streamflow

Impacted (continued)									Composite hydrograph
% (13)	Inches (14)	cfs (15)	% (16)	Inches (17)	cfs (18)	% (19)	Inches (20)	cfs (21)	cfs (22)
									.00
									.00
									.00
									.00
									.34
									.97
									1.64
									2.61
									3.87
									5.35
									6.82
									9.09
									10.23
									9.09
									6.82
									4.21
									2.44
									1.14
									.34
									.00

(5),(8),(11),(14),(17),(20)	Digitized excess water distribution (%) multiplied by water available for annual streamflow gives flow in inches.
(6),(9),(12),(15),(18),(21)	To convert from area inches to cfs, the area-inch hydrograph is multiplied by:

$$\frac{\text{Total watershed area (in acres)}}{\text{(12 in/ft) (1.98) (Number of days in interval)}}$$

(22)	Sum of columns (6), (9), (12), (15), (18), and (21) gives the composite hydrograph for the entire watershed in cfs.

WORKSHEET

Proposed condition hydrograph

(1) Watershed name Horse Creek

Date or Interval (3)	Distribution of water								
	Unimpacted						Impacted		
	Forested						Forested		
	% (4)	inches (5)	cfs (6)	% (7)	inches (8)	cfs (9)	% (10)	inches (11)	cfs (12)
APRIL 8	.0000	.00	.00				.0000	.00	.00
14	.0000	.00	.00				.0000	.00	.00
20	.0000	.00	.00				.0000	.00	.00
26	.0000	.00	.00				.0000	.00	.00
MAY 2	.0050	.02	.08				.0050	.01	.04
8	.0150	.05	.21				.0150	.02	.08
14	.0250	.09	.38				.0250	.03	.13
20	.0400	.14	.59				.0400	.04	.17
26	.0600	.21	.88				.0600	.07	.29
JUNE 1	.0825	.29	1.22				.0825	.09	.38
7	.1050	.37	1.56				.1050	.12	.51
13	.1400	.49	2.06				.1400	.15	.63
19	.1575	.55	2.31				.1575	.17	.72
25	.1400	.49	2.06				.1400	.15	.63
JULY 1	.1050	.37	1.56				.1050	.12	.51
7	.0650	.23	.97				.0650	.07	.29
13	.0375	.13	.55				.0375	.04	.17
19	.0175	.06	.25				.0175	.02	.08
25	.0050	.02	.08				.0050	.01	.04
31	.0000	.00	.00				.0000	.00	.00

Item or Col. No.	Notes
(1)	Identification of watershed or watershed subunit.
(2)	Descriptions of hydrologic regions and provinces are given in text.
(3)	Supplied by user. Either date snowmelt begins or date of peak snowmelt runoff.
(4),(7), (10),(13), (16),(19)	Digitized excess water distribution (%) from tables III.11 to III.22 for forested and open condition. Interpolate between forested and open for other conditions.

III.8

for snow dominated regions

(2) Hydrologic region 4

available for annual streamflow									Composite hydrograph
Impacted (continued)									
Clearcut									
% (13)	Inches (14)	cfs (15)	% (16)	Inches (17)	cfs (18)	% (19)	Inches (20)	cfs (21)	cfs (22)
.0000	.00	.00							.00
.0025	.03	.13							.13
.0075	.10	.42							.42
.0250	.34	1.43							1.43
.0425	.57	2.40							2.52
.0650	.88	3.70							3.99
.0825	1.11	4.67							5.18
.1075	1.45	6.10							6.86
.1475	1.99	8.38							9.55
.1650	2.23	9.39							10.99
.1450	1.96	8.25							10.32
.1150	1.55	6.52							9.21
.0625	.84	3.54							6.57
.0250	.34	1.43							4.12
.0075	.10	.42							2.49
.0000	.00	.00							1.26
.0000	.00	.00							.72
.0000	.00	.00							.33
.0000	.00	.00							.12
.0000	.00	.00							.00

(5),(8), (11),(14), (17),(20)	Digitized excess water distribution (%) multiplied by water available for annual streamflow gives flow in inches.
(6),(9), (12),(15), (18),(21)	To convert from area inches to cfs, the area-inch hydrograph is multiplied by:
(22)	Sum of columns (6), (9), (12), (15), (18), and (21) gives the composite hydrograph for the entire watershed in cfs.

$$\frac{\text{Total watershed area (in acres)}}{\text{(12 in/ft) (1.98) (Number of days in interval)}}$$

WORKSHEET IV.1

Soil characteristics for the Horse Creek watershed

Soil group		Percent sand 2.0-0.1 mm	Percent very fine sand 0.10-0.05 mm	Percent "coarse silt" 0.062-0.05 mm[1]	Percent silt 0.05-0.002 mm	Percent clay <0.002 mm	Percent organic matter	Soil structure		Soil permeability	
								MSLE code	Descrip-tive	MSLE code	Inches per hour
1	Topsoil	10	40	12	30	20	7.0	3	MEDIUM TO COARSE GRANULAR	5	0.06-0.2
	Subsoil	20	30	8	25	25	1.0	4	PRISMATIC	5	0.06-0.2
2	Topsoil	50	25	4	15	10	4.0	4	BLOCKY	4	0.2-0.6
	Subsoil	40	20	3	15	25	1.0	4	BLOCKY	5	0.06-0.2
3	Topsoil	65	15	2	10	10	4.0	2	FINE GRANULAR	3	0.6-2.0
	Subsoil	70	15	9	5	10	2.0	3	COARSE GRANULAR	2	2.0-6.0

[1] The "coarse silt" particle size group is not part of the USDA classification system, but 0.062 mm represents an upper limit of particle size that is used when estimating suspended sediment transport in streams. For this use only the "coarse silt" size within the USDA very fine sand classification is presented.

WORKSHEET IV.2

Horse Creek watershed erosion response unit management data for use in the MSLE and sediment delivery index, hydrographic area 3, proposed plan.

Erosion response unit	Slope length of disturbed area (ft)	Slope gradient of disturbed area (%)	Length of road section (ft)	Average width of disturbance (ft)	Area (sq.ft.)	Area (acres) [1]
1. CC 3.1	100	38				8.0
2. CC 3.2	150	30				6
3. L 3.1	68	5		210		0.33
4. R 3.1			680	17.8		0.31
5. CUT	4.8	66.7		2.9		
6. BED	12.0	0.5		12.0		
7. FILL	4.8	66.7		2.9		
8. R 3.2 [2]			30	17.8		0.01
9. CUT	4.8	66.7		2.9		
10. BED	12.0	0.5		12.0		
11. FILL	4.8	66.7		2.9		
12.						
13.						
14.						
15.						
16.						
17.						
18.						
19.						
20.						
21.						
22.						
23.						
24.						
25.						

[1] 1 acre = 43,560 ft^2

[2] This road section crosses a stream. It is separated from the rest of the road because sediment is delivered directly into a channel.

WORKSHEET IV.2--continued

	Area with surface residues 3/			Open area 3/				
	Percent of total area	Percent of surface with mulch	Percent of area with fine roots 4/	Percent of total area	Percent of surface with mulch	Percent of area with fine roots 4/	Are open areas separated by filter strips?	Percent of total area with canopy
1.	65	90	90	35	10	90	YES	0
2.	60	90	85	40	10	85	YES	0
3.	0	—	—	100	UNKNOWN	UNKNOWN	NO	0
4.								
5.	100	70	50	0	—	—		90
6.	0	—	—	100	0	0	NO	0
7.	100	70	50	0	—	—		90
8.								
9.	100	70	50	0	—	—		90
10.	0	—	—	100	0	0	NO	0
11.	100	70	50	0	—	—		90
12.								
13.								
14.								
15.								
16.								
17.								
18.								
19.								
20.								
21.								
22.								
23.								
24.								
25.								

3/ *Values at end of first year after the disturbance.*

4/ *Not applicable to scalped areas until vegetation is reestablished.*

3 of 3

WORKSHEET IV.2--continued

	Average minimum height of canopy (m)	Time for recovery (mo)	Average dist. from disturbance to stream channel (ft)	Overall slope shape between disturbance and channel	Percent ground cover in filter strip	Surface roughness (qualitative)	Texture of eroded material ($ silt + clay)[5]	Percent slope between disturbance and channel
1.	—	UNKNOWN	15	STRAIGHT	90	MODERATE	45	38
2.	—	UNKNOWN	15	STRAIGHT	90	MODERATE	45	30
3.	—	UNKNOWN	0	STRAIGHT	0	SMOOTH	45	5
4.		1 YEAR	100	STRAIGHT	89	MODERATE	48	30
5.	0.5							
6.	—							
7.	0.5							
8.		1 YEAR	0	STRAIGHT	0	SMOOTH	48	67
9.	0.5							
10.	—							
11.	0.5							
12.								
13.								
14.								
15.								
16.								
17.								
18.								
19.								
20.								
21.								
22.								
23.								
24.								
25.								

---

[5] *It has been assumed that ½ of the clay remains on-site as stable aggregates and that the rest of the clay plus very fine sand and silt enter the sediment delivery system.*

WORKSHEET IV.3

Estimates of soil loss and delivered sediment by erosion response unit
for hydrographic area 3 of Horse Creek watershed

Erosion response unit [1]	Soil unit [2]	R	K	LS	VM	Area (acres)	Surface soil loss (tons/yr)	SD_1	Delivered sediment (tons/yr)
CC 3.1	T2	45	0.28	11.4	0.02	8.0	23.0	0.02	0.5
CC 3.2	T2	45	0.28	9.6	0.02	6.0	15.0	0.02	0.3
L 3.1	T2	45	0.28	0.44	0.89	0.3	1.5	0.11	0.2
R 3.1	S2	45	0.30	4.5	0.97	0.3	18.0	0.01	0.2
R 3.2	S2	45	0.30	4.3 [3]	0.97	0.01	0.6	0.22	0.1

[1] CC - *Clearcut*
L - *Landing*
R - *Road*

[2] T - *Topsoil*
S - *Subsoil*

[3] *Average of two LS values, one for each half of the road, starting at the center line and including a fill slope.*

WORKSHEET IV.4

Estimated VM factors for silvicultural erosion response units
Horse Creek watershed, hydrographic area 3.

	Logging residue area					Open area						
Erosion response unit	Fraction of total area	Mulch (duff & residue)	Canopy	Roots	Sub VM	Fraction percent of total area	Mulch (duff & residue)	Canopy	Roots	Filter strip	Sub VM	Total VM[1]
CC 3.1	0.65	0.08	1.0	0.10	0.005	0.35	0.78	1.0	0.10	0.5	0.014	0.02
CC 3.2	0.60	0.08	1.0	0.11	0.005	0.40	0.78	1.0	0.11	0.5	0.014	0.02

[1] *Enter on worksheet IV.3.*

WORKSHEET IV.5

Example of estimated monthly change in VM factor following construction for road cuts and fills in Horse Creek watershed, hydrographic area 3.

Month	Percent cover and VM subfactors						Monthly VM
	Mulch		Canopy		Roots		
	Percent	VM	Percent	VM	Percent	VM	
Sep.[1/]	0	1.00	0	1.00			1.00
Oct.[3/]	8	0.80	12	0.88			0.70
Nov.	20	0.59	22	0.80			0.47
Dec.[2/]	—		—				—
Jan.[2/]	—		—				—
Feb.[2/]	—		—				—
March[2/]	—		—				—
April[4/]	10	0.78	10	0.90			0.70
May[4/]	28	0.50	20	0.82			0.41
June[5/]	50	0.32	70	0.41	20	0.35	0.05
July[5/]	60	0.25	83	0.30	40	0.27	0.02
Aug.	70	0.18	90	0.25	50	0.22	0.01

[1/] Begin seeding, enough rain is assumed to ensure seed germination.

[2/] Snow cover with no erosive precipitation.

[3/] Significant canopy effect developing.

[4/] Snowmelt runoff occurs, some protective vegetative cover lost during winter.

[5/] Significant root network developing from seeded grass.

WORKSHEET IV.6

Weighting of VM values for roads in
Horse Creek watershed, hydrographic area 3.

Erosion response unit	Cut or fill		Roadbed		Fill		Weighted
	Fraction of total width	VM	Fraction of total width	VM	Fraction of total width	VM	VM
R 3.1	(0.1629)	(0.42)	+ (0.6743)	(1.24)	+ (0.1629)	(0.42)	= 0.97
R 3.2	(0.1629)	(0.42)	+ (0.6742)	(1.24)	+ (0.1629)	(0.42)	= 0.97

WORKSHEET IV.7

Factors for sediment delivery index from erosion response units in

Horse Creek watershed, hydrographic area 3.

Erosion response unit	Water availability[1]	Texture of eroded material	Percent ground cover between disturbance and channel	Slope shape code	Distance (edge of disturbance to channel) (ft)	Surface roughness code	Slope gradient (%)	Specific site factor	Percent of total area for polygon	SDI[5]
CC3.1	0.004 [2]	45	90	2	15	2	38	—	12.1	0.02
CC3.2	0.006 [3]	45	90	2	15	2	30	—	11.8	0.02
L3.1	0.003 [3]	45	90	2	20	2	5	—	9.3	0.01
R3.1	0.004 [4]	48	89	2	100	2	30	—	7.0	0.01
R3.2	0.004 [4]	48	0	2	1	1	67	—	35.1	0.22

[1] *Maximum 15 min. annual storm of 1.75 in/hr.*

[2] *Infiltration rate of 0.26 in/hr (based on soil permeability).*

[3] *Ilfiltration rate of 0.10 in/hr (based on soil permeability).*

[4] *Infiltration rate of 0.05 in/hr (based on soil permeability).*

[5] *Enter on worksheet IV.3.*

WORKSHEET IV.8

Estimated tons of sediment delivered to a channel for each hydrographic area and type of disturbance for Horse Creek watershed

proposed management

Hydrographic area	Cutting units					Landings			Roads					Total tons/yr	Percent
	CC_1	CC_2	CC_3	CC_4	CC_5	L_1	L_2	L_3	R_1	R_2	R_3	R_4	R_5		
1	0.0	0.0				0.0	0.0	0.0	0.0	0.0				0.0	0.0
2	0.3	0.2	0.3	0.2		0.1			0.1	0.2	0.1	0.1		1.6	9.0
3	0.5	0.3				0.2			0.2	0.1				1.3	7.3
4	0.0					0.0	0.0		0.0	0.0	0.1			0.1	0.6
5	0.3	0.1				0.0			0.0	0.1	0.1			0.6	3.4
6	–								0.0	0.0	0.1	0.1		0.2	1.1
7	0.0								0.0	0.1				0.1	0.6
8	0.1								0.1	0.1	0.1	0.1		0.5	2.8
9	0.2	0.2							0.1					0.5	2.8
10	0.2	0.3				0.2			0.2	0.1	0.1			1.1	6.2
11	0.0								0.0	0.2	0.2	0.1	0.1	0.6	3.4
12	0.1	0.0				0.0	0.0	0.0	0.1	0.2				0.4	2.3
13	–								0.2	0.1	0.3			0.6	3.4
14	0.3								0.2	0.1	0.3			0.6	3.4
15	0.0					0.0			0.0	0.3	0.2	0.1		0.6	3.4
16	0.3					0.0			0.0	0.3	0.1			0.7	4.0
17	0.0								0.0	0.3	0.2			0.5	2.8
18	0.0					0.0	0.0		0.0	0.0	0.2	0.1		0.3	1.7
19	0.0								0.1					0.1	0.6
20	0.3	0.1				0.0			0.1					0.5	2.8
26[1]	0.0	0.3				0.1	0.0	0.0	0.2					0.6	3.4
27	0.0	0.5	0.3	0.3	0.4	0.1			0.0	0.2	0.1	0.1		2.0	11.3
28	0.0	0.3	0.1	0.3					0.2	0.1	0.2	0.1		1.3	7.3
29	0.3	0.3	0.1	0.4		0.0			0.2	0.1				1.4	7.9
30	0.0	0.0				0.0			0.0	0.0				0.0	0.0
31	0.0	0.1	0.5			0.0			0.0	0.0				0.6	3.4
32	0.2	0.2				0.2			0.3	0.2				0.9	5.1
Column total	3.1	2.7	1.3	1.2	0.4	0.9	0.0	0.0	2.3	2.8	2.1	0.8	0.1	17.7	
Disturbance total	8.7					0.9			8.1						
Percent	49.2					5.1			45.8						

[1] Hydrographic areas 21, 22, 23, 24, and 25 have no activities.

WORKSHEET IV.2

Horse Creek watershed erosion response unit management data for use in the MSLE and sediment delivery index, hydrographic area 3, revised plan.

Erosion response unit	Slope length of disturbed area (ft)	Slope gradient of disturbed area (%)	Length of road section (ft)	Average width of disturbance (ft)	Area (sq.ft.)	Area (acres) [1]
1. CC3.1	422	38				8
2. CC3.2	80	30				6
3. L3.1	68	5		210		0.33
4. R3.1			680	20		0.31
5. CUT	4.8	66.7		4.0		
6. BED	12.0	0.5		12.0		
7. FILL	4.8	66.7		4.0		
8. R3.2 [2]			30	20		0.01
9. FILL	4.8	66.7		4.0		
10. BED	12.0	0.5		12.0		
11. FILL	4.8	66.7		4.0		
12.						
13.						
14.						
15.						
16.						
17.						
18.						
19.						
20.						
21.						
22.						
23.						
24.						
25.						

[1] 1 acre = 43,560 ft^2

[2] This road section crosses a stream. It is separated from the rest of the road because sediment is delivered directly into a channel.

WORKSHEET IV.2--continued

	Area with surface residues 3/			Open area 3/				
	Percent of total area	Percent of surface with mulch	Percent of area with fine roots 4/	Percent of total area	Percent of surface with mulch	Percent of area with fine roots 4/	Are open areas separated by filter strips?	Percent of total area with canopy
1.	65	90	90	35	10	90	YES	0
2.	60	90	85	40	10	85	YES	0
3.	0	—	—	100	UNKNOWN	UNKNOWN	NO	0
4.								
5.	100	70	50	0	—	—	—	90
6.	0	—	—	100	100 5/	0	NO	0
7.	100	70	50	0	—	—	—	90
8.								
9.	100	70	50	0	—	—	—	90
10.	0	—	—	100	100 5/	0	NO	0
11.	100	70	50	0	—	—	—	90
12.								
13.								
14.								
15.								
16.								
17.								
18.								
19.								
20.								
21.								
22.								
23.								
24.								
25.								

3/ *Values are for the end of the first year following disturbance.*

4/ *Not applicable to scalped areas until vegetation is reestablished.*

5/ *Six inches of crushed gravel, 3/4 inch or smaller in size, placed on running surface.*

WORKSHEET IV.2--continued

	Average minimum height of canopy (m)	Time for recovery (mo)	Average dist. from disturbance to stream channel (ft)	Overall slope shape between disturbance and channel	Percent ground cover in filter strip	Surface roughness (qualitative)	Texture of eroded material 6/ (% silt + clay)	Percent slope between disturbance and channel
1.	—	UNKNOWN	15	STRAIGHT	90	MODERATE	45	38
2.	—	UNKNOWN	15	STRAIGHT	90	MODERATE	45	30
3.	—	UNKNOWN	20	STRAIGHT	90	MODERATE	45	5
4.		1 YEAR	100	STRAIGHT	89	MODERATE	48	30
5.	0.5							
6.	—							
7.	0.5							
8.		1 YEAR	0	STRAIGHT	0	SMOOTH	48	67
9.	0.5							
10.	—							
11.	0.5							
12.								
13.								
14.								
15.								
16.								
17.								
18.								
19.								
20.								
21.								
22.								
23.								
24.								
25.								

6/ *It has been assumed that ½ of the clay remains on-site as stable aggregates and that the rest of the clay plus very fine sand and silt enter the sediment delivery system.*

WORKSHEET IV.3

Estimates of soil loss and delivered sediment by erosion response unit
for hydrographic area 3 of Horse Creek watershed

Erosion response unit [1]	Soil unit [2]	R	K	LS	VM	Area (acres)	Surface soil loss (tons/yr)	SD_1	Delivered sediment (tons/yr)
CC 3.1	T 2	45	0.28	11.4	0.02	8.0	23.0	0.02	0.5
CC 3.2	T 2	45	0.28	9.6	0.02	6.0	15.0	0.02	0.3
L 3.1	T 2	45	0.28	0.44	0.89	0.3	1.5	0.01	0.01
R 3.1	S 2	45	0.30	4.5	0.17	0.3	3.0	0.01	0.03
R 3.2	S 2	45	0.30	4.3 [3]	0.17	0.01	0.1	0.22	0.02

[1] CC - Clearcut
L - Landing
R - Road

[2] T - Topsoil
S - Subsoil

[3] Average of two LS values, one for each half of the road, starting at the center line and including a fill slope.

WORKSHEET IV.4

Estimated VM factors for silvicultural erosion response units
Horse Creek watershed, hydrographic area 3.

Logging residue area						Open area						
Erosion response unit	Fraction of total area	Mulch (duff & residue)	Canopy	Roots	Sub VM	Fraction percent of total area	Mulch (duff & residue)	Canopy	Roots	Filter strip	Sub VM	Total VM[1]
CC3.1	0.65	0.08	1.0	0.10	0.005	0.35	0.78	1.0	0.10	0.5	0.014	0.02
CC3.2	0.60	0.08	1.0	0.11	0.005	0.40	0.78	1.0	0.11	0.5	0.017	0.02
R3.1 CUT												0.42[3]
BED						1.00	0.005[2]	1.0			0.005	0.005
FILL												0.42[3]
R3.2 FILL												0.42[3]
BED						1.00	0.005[2]	1.0			0.005	0.005
FILL												0.42[3]

[1] *Enter on worksheet IV.3.*

[2] *Six inches of crushed gravel is assumed to have the indicated value.*

[3] *Average VM from worksheet IV.5 for proposed plan.*

WORKSHEET IV.6

Weighting of VM values for roads in
Horse Creek watershed, hydrographic area 3.

Erosion response unit	Cut or fill		Roadbed		Fill		Weighted VM
	Fraction of total width	VM	Fraction of total width	VM	Fraction of total width	VM	
R3.1	(0.20)	(0.42)	+ (0.60)	(0.005)	+ (0.20)	(0.42)	= 0.17
R3.2	(0.20)	(0.42)	+ (0.60)	(0.005)	+ (0.20)	(0.42)	= 0.17

WORKSHEET IV.7

Factors for sediment delivery index from erosion response units in

Horse Creek watershed, hydrographic area 3.

Erosion response unit	Water availability [1]	Texture of eroded material	Percent ground cover between disturbance and channel	Slope shape code	Distance (edge of disturbance to channel) (ft)	Surface roughness code	Slope gradient (%)	Specific site factor	Percent of total area for polygon	SDI [5]
CC 3.1	0.004 [2]	45	90	2	15	2	38	—	12.1	0.02
CC 3.2	0.006 [2]	45	90	2	15	2	30	—	11.8	0.02
L 3.1	0.003 [3]	45	0	2	1	1	5	—	28.2	0.11
R 3.1	0.004 [4]	48	89	2	100	2	30	—	7.0	0.01
R 3.2	0.004 [4]	48	0	2	1	1	67	—	35.1	0.22

---

[1] *Maximum 15 min. annual storm of 1.75 in/hr.*

[2] *Infiltration rate of 0.26 in/hr (based on soil permeability).*

[3] *Infiltration rate of 0.10 in/hr (based on soil permeability).*

[4] *Infiltration rate of 0.05 in/hr (based on soil permeability).*

[5] *Enter on worksheet IV.3.*

WORKSHEET IV.8

Estimated tons of sediment delivered to a channel for each hydrographic area and type of disturbance for Horse Creek watershed, revised plan

Hydrographic area	Cutting units					Landings			Roads					Total tons/yr	Percent
	CC_1	CC_2	CC_3	CC_4	CC_5	L_1	L_2	L_3	R_1	R_2	R_3	R_4	R_5		
1	0.0	0.0				0.0	0.0	0.0	0.0	0.0				0.0	0.0
2	0.3	0.2	0.3	0.2		0.0			0.02	0.03	0.02	0.02		1.09	11.1
3	0.5	0.3				0.01			0.03	0.02				0.86	9.1
4	0.0					0.0	0.0		0.0	0.0	0.02			0.02	0.2
5	0.3	0.1				0.0			0.0	0.02	0.02			0.44	4.7
6									0.0	0.0	0.02	0.02		0.04	0.4
7	0.0								0.0	0.02				0.02	0.2
8	0.1								0.02	0.02	0.02	0.02		0.18	1.9
9	0.2	0.2							0.02					0.42	4.5
10	0.2	0.3				0.01			0.03	0.02	0.02			0.58	6.2
11	0.0								0.0	0.03	0.03	0.02	0.02	0.10	1.1
12	0.1	0.0				0.0	0.0	0.0	0.02	0.03				0.15	1.6
13									0.03	0.02	0.04			0.09	1.0
14	0.5								0.03	0.02	0.0			0.37	3.8
15	0.0					0.0			0.0	0.04	0.03	0.02		0.09	1.0
16	0.5					0.0			0.0	0.04	0.02			0.38	3.9
17	0.0								0.0	0.04	0.03			0.07	0.7
18	0.0					0.0	0.0		0.0	0.0	0.03	0.02		0.05	0.5
19	0.0								0.02					0.02	0.2
20	0.3	0.1				0.0			0.02					0.42	4.5
26 3/	4/	4/				5/	5/	5/	6/			6/		0.0	0.0
27	0.0	0.5	0.3	4/	0.4	5/			0.0	0.03	0.02	0.02		1.25	13.3
28	0.0	0.3	0.1	0.3					0.03	0.02	0.03			0.80	8.5
29	0.3	0.3	0.1	0.4		0.0			0.03	0.02				1.15	12.2
30	0.0	0.0				0.0			0.0	0.0				0.0	0.0
31	0.0	0.1	0.5			0.0			0.0	0.0				0.60	6.4
32	0.2	0.0				0.01			0.04	0.03				0.28	3.0
Column total	3.5	2.4	1.3	0.9	0.4	0.03	0.0	0.0	0.34	0.45	0.35	0.14	0.02	9.83	
Disturbance total	8.5					0.03			1.30						
Percent	86.5					0.3			13.2						

1/ *Values have changed from proposed plan due to application of controls for landings.*
2/ *Values have changed from proposed plan due to application of controls for roads.*
3/ *Hydrographic areas 21, 22, 23, 24, and 25 have no activities.*
4/ *Clearcut erosion response units eliminated by controls for mass wasting.*
5/ *Landing erosion response units eliminated by controls for mass wasting.*
6/ *Road erosion response units eliminated by controls for mass wasting.*

WORKSHEET V.1

Debris avalanche-debris flow natural factor evaluation form

Index	Slope gradient	Soil depth	Subsurface drainage characteristics	Soil texture	Bedding structure and orientation	Slope configuration	Precipitation input
High	30	3	[✓ 3]	3	3	3	12
Medium	[✓ 15]	[✓ 2]	2	[✓ 2]	[✓ 2]	[✓ 2]	[✓ 5]
Low	5	1	1	0	1	1	3

Factor summation table

Gross hazard index	Factor range	Natural
High	Greater than 44	31
Medium	21 - 44	
Low	Less than 21	

WORKSHEET V.2

Debris avalanche-debris flow management related factor evaluation form

Index	Vegetation cover removal	Roads and skidways	Harvest methods
High	[✓ 8]	[✓ 20]	[✓ 3]
Medium	5	8	2
Low	2	2	0

Factor summation table

Gross hazard index	Range	Natural + management
High	Greater than 44	31+31 = 62
Medium	21 - 44	
Low	Less than 21	

WORKSHEET V.5

Estimation of volume per failure

	Debris avalanche-debris flow						Slump earthflow					
Slide Number	Natural	Man-induced	Length (ft)	Width (ft)	Depth (ft)	Volume (ft^3)	Natural	Man-induced	Length (ft)	Width (ft)	Depth (ft)	Volume (ft^3)
Horse	Creek											
1	X		84	28	1.5	3,528						
Mule	Creek											
1		X	80	24	1.5	3,880						
2		X	129	26	1.5	5,031						
3		X	121	17	1.5	3,086						
4		X	113	18	1.5	3,041						
5		X	95	23	1.5	3,278						
1	X		115	19	1.5	3,280						

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WORKSHEET V.6

Estimation of soil mass movement delivered to the stream channel

(1) Watershed name Mule Creek

Factor (2)		Soil mass movement type			
		Debris avalanche-Debris flow		Slump flow	
		Natural (3)	Man-Induced (4)	Natural (5)	Man-Induced (6)
1 Total volume (V_t) in ft^3		3280	17205	—	—
2 Total number of failures (N)		1	5	—	—
3 Average volume per failure (VA)(ft^3)		3280	3441		
4 Number of failures per slope class	a	1	2		
	b	—	2		
	c	—	1		
5 Number of failures per slope position category	a'			—	—
	b'			—	—
	c'			—	—
	d'			—	—
6 Total volume per slope class or position category (V) in ft^3 $V = V_A \times N$	V_a $V_{a'}$	3280	6882	—	—
	V_b $V_{b'}$	—	6882	—	—
	V_c $V_{c'}$	—	3441	—	—
	$V_{d'}$			—	—
7 Unit weight of dry soil material (γ_d) (lb/ft^3)		99	99	—	—

WORKSHEET V.6--continued

8 Total weight per slope class or position category (W) in tons $W = \frac{V \times Y_d}{2,000}$	W_a W_a'	163	341	—	—
	W_b W_b'	—	341	—	—
	W_c W_c'	—	171	—	—
	W_d'			—	—
9 Slope irregularity--smooth or irregular		smooth	smooth	—	—
10 Delivery potential (D) as a decimal percent for slope class or position category	D_a D_a'	0.62	0.50	—	—
	D_b D_b'	—	0.30	—	—
	D_c D_c'	—	0.15	—	—
	D_d'			—	—
11 Total weight of soil delivered per slope class or position category (S) in tons S = W x D	S_a S_a'	101	171	—	—
	S_b S_b'	—	102	—	—
	S_c S_c'	—	26	—	—
	S_d'			—	—
12 Total quantity of sediment delivered to the stream channel in tons		101 (400)	299	—	—
13 Acceleration factor (f) f = $TS_{\text{silvicultural activity}}/TS_{\text{natural}}$		3		—	
14 Estimated increase in soil delivered to the stream channel due to the proposed silvicultural activity (TS) in tons $TS_{\text{silvicultural activity}} = TS_{\text{natural}} \times f$		—		—	

WORKSHEET V.6

Estimation of soil mass movement delivered to the stream channel

(1) Watershed name Horse Creek

Factor (2)		Soil mass movement type			
		Debris avalanche-Debris flow		Slump flow	
		Natural (3)	Man-induced (4)	Natural (5)	Man-induced (6)
1 Total volume (V_t) in ft^3		3528	—	—	—
2 Total number of failures (N)		1	—	—	—
3 Average volume per failure (VA)(ft^3)		3528	—	—	—
4 Number of failures per slope class	a	—	—		
	b	1	—		
	c	—	—		
5 Number of failures per slope position category	a'			—	—
	b'			—	—
	c'			—	—
	d'			—	—
6 Total volume per slope class or position category (V) in ft^3	V_a $V_{a'}$	—	—	—	—
$V = V_A \times N$	V_b $V_{b'}$	3528	—	—	—
	V_c $V_{c'}$	—	—	—	—
	$V_{d'}$			—	—
7 Unit weight of dry soil material (γ_d) (lb/ft^3)		90	—	—	—

WORKSHEET V.6--continued

8 Total weight per slope class or position category (W) in tons $W = \frac{V \times \gamma_d}{2,000}$	W_a $W_{a'}$	—	—	—	—
	W_b $W_{b'}$	159	—	—	—
	W_c $W_{c'}$			—	—
	$W_{d'}$	—	—	—	—
9 Slope irregularity--smooth or irregular		smooth	—	—	—
10 Delivery potential (D) as a decimal percent for slope class or position category	D_a $D_{a'}$	—	—	—	—
	D_b $D_{b'}$	0.40	—	—	—
	D_c $D_{c'}$	—	—	—	—
	$D_{d'}$			—	—
11 Total weight of soil delivered per slope class or position category (S) in tons $S = W \times D$	S_a $S_{a'}$	—	—	—	—
	S_b $S_{b'}$	64	—	—	—
	S_c $S_{c'}$	—	—	—	—
	$S_{d'}$			—	—
12 Total quantity of sediment delivered to the stream channel in tons		64	—	—	—
13 Acceleration factor (f) $f = TS_{\text{silvicultural activity}}/TS_{\text{natural}}$		From Mule Creek 3.0		—	
14 Estimated increase in soil delivered to the stream channel due to the proposed silvicultural activity (TS) in tons $TS_{\text{silvicultural activity}} = TS_{\text{natural}} \times f$		192		—	

WORKSHEET V.2

Debris avalanche-debris flow management related factor evaluation form

Index	Vegetation cover removal	Roads and skidways	Harvest methods
High	8	20	[✓ 3]
Medium	5	8	2
Low	[✓ 2]	[✓ 2]	0

Factor summation table

Gross hazard index	Range	Natural + management
High	Greater than 44	31 + 7 = 38
Medium	21 - 44	
Low	Less than 21	

WORKSHEET VI.1

Suspended sediment quantification for Horse Creek
(Pre and Post for Proposed and Revised Silvicultural Plans)

(1) Time increment			(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(a) With hydrographs use date; with flow duration curves use % of 365 days	(b) Number of days pre-silvicultural activity	(c) Number of days post-silvicultural activity	Pre-silvicultural activity flow (cfs)	Suspended sediment concentration (mg/l)	Total increment suspended sediment cols. (2) x (3) x (1.b) x .0027 (tons)	Post-silvicultural activity flow (cfs)	Suspended sediment concentration (mg/l)	Total increment post-silvicultural activity suspended sediment cols. (5) x (6) x (1.c) x .0027 (tons)	Maximum concentrations from selected water quality objective (mg/l)	Maximum sediment discharge cols. (2) x (8) x (1.b) x .0027 (tons)
APR 8	6	6				0.00	—	—	—	—
14	6	6				0.13	0.5	NEGLI	—	—
20	6	6				0.42	1.2	0.01	—	—
26	6	6	0.00	—		1.43	2.5	0.06	—	—
MAY 2	6	6	0.34	1.0	0.01	2.52	3.6	0.15	31.0	0.17
8	6	6	0.97	2.0	0.03	3.99	4.9	0.32	32.0	0.50
14	6	6	1.64	2.8	0.07	5.18	5.8	0.49	32.8	0.87
20	6	6	2.61	3.7	0.16	6.86	6.9	0.77	33.7	1.43
26	6	6	3.87	4.8	0.30	9.55	8.6	1.32	34.8	2.18
JUN 1	6	6	5.35	5.9	0.51	10.99	9.4	1.67	35.9	3.11
7	6	6	6.82	6.9	0.76	10.32	9.0	1.50	36.9	4.08
13	6	6	9.09	8.3	1.22	9.21	8.4	1.25	38.3	5.64
19	6	6	10.23	8.9	1.48	6.57	6.7	0.72	38.9	6.45
25	6	6	9.09	8.3	1.22	4.12	5.0	0.33	38.3	5.64
JUL 1	6	6	6.82	6.9	0.76	2.49	3.6	0.15	36.9	4.08
7	6	6	4.21	5.1	0.35	1.26	2.3	0.05	35.1	2.39
13	6	6	2.44	3.6	0.14	0.72	1.6	0.02	33.6	1.33
19	6	6	1.14	2.2	0.04	0.33	1.0	0.01	32.2	0.60
25	6	6	0.34	1.0	0.01	0.12	0.5	NEGLI	31.0	0.17
31	6	6	0.00	—	—	0.00	—	—	—	

(Totals are rounded to nearest tenth)

Total 7.1 tons/yr

Total 8.8 tons/yr

Total 38.6 tons/yr

Summary: Total pre-silvicultural activity suspended sediment discharge = 7.1
Total post-silvicultural activity suspended sediment discharge = 8.8
Total maximum sediment discharge = 38.6

WORKSHEET VI.2

Bedload sediment quantification for Horse Creek
(Pre and Post for Proposed and Revised Silvicultural Plans)

(1) Time increment			(2) Pre-silvicultural activity flow	(3) Bedload transport rate	(4) Total pre-silvicultural activity bedload discharge cols. (3) x (1.b)	(5) Post-silvicultural activity flow	(6) Bedload transport rate	(7) Post-silvicultural activity bedload discharge cols. (6) x (1.c)
(a) With hydrographs use date; with flow duration curves use % of 365 days	(b) Number of days pre-silvicultural activity	(c) Number of days post-silvicultural activity	Q_{pre} (cfs)	i_{bpre} (tons/day)	B_{pre}	Q_{post} (cfs)	i_{bpost} (tons/day)	B_{post}
APR 8	6	6				0.00	—	
14	6	6				0.13	NEGLI	
20	6	6				0.42	NEGLI	
26	6	6	0.00	—		1.43	.001	.01
MAY 2	6	6	0.34	NEGLI		2.52	.003	.02
8	6	6	0.97	NEGLI		3.99	.008	.05
14	6	6	1.64	.001	.01	5.18	.013	.08
20	6	6	2.61	.003	.02	6.86	.025	.15
26	6	6	3.87	.007	.04	9.55	.051	.31
JUN 1	6	6	5.35	.014	.09	10.99	.069	.42
7	6	6	6.82	.024	.15	10.32	.060	.36
13	6	6	9.09	.046	.27	9.21	.047	.28
19	6	6	10.23	.059	.36	6.57	.023	.14
25	6	6	9.09	.046	.27	4.12	.008	.05
JUL 1	6	6	6.82	.024	.15	2.49	.003	.02
7	6	6	4.21	.009	.05	1.26	.001	.004
13	6	6	2.44	.003	.02	0.72	NEGLI	
19	6	6	1.14	NEGLI		0.33	NEGLI	
25	6	6	0.34	NEGLI		0.12	NEGLI	
31	6	6	0.00	—		0.00		

(Totals are rounded to nearest tenth)

Total 1.4 tons/yr

Total 1.9 tons/yr

Summary: Total pre-silvicultural activity bedload discharge = 1.4
Total post-silvicultural activity bedload discharge = 1.9

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WORKSHEET VI.3

Sediment prediction worksheet summary

Subdrainage name Horse Creek (Proposed Silvicultural Plan) Date of analysis 6/2/78

Suspended Sediment Discharge

A. Pre-silvicultural activity total potential suspended sediment discharge (total col. (4), wksht. VI.1) (tons/yr) 7.1

B. Post-silvicultural activity total potential suspended sediment discharge (total col. (7), wksht. VI.1) (due to streamflow increases) (tons/yr) 8.8

C. Maximum allowable potential suspended sediment discharge (total col. (9), wksht. VI.1) (tons/yr) 38.6

D. Potential introduced sediment sources: (delivered)

1. Surface erosion (tons/yr) 17.7
2. Soil mass movement (coarse) (tons/yr) 146
3. Median particle size (mm) 10
4. Soil mass movement--washload (silts and clays) (tons/yr) 46

Bedload Discharge (Due to increased streamflow)

E. Pre-silvicultural activity potential bedload discharge (tons/yr) 1.4

F. Post-silvicultural activity potential bedload discharge (due to increased streamflow) (tons/yr) 1.9

Total Sediment and Stream Channel Changes

G. Sum of post-silvicultural activity suspended sediment + bedload discharge (other than introduced sources) (tons/yr) 10.7 (sum B + F)

H. Sum of total introduced sediment (D) = (D.1 + D.2 + D.4) (tons/yr) 209.7

I. Total increases in potential suspended sediment discharge

1. (B + D.1 + D.4) - (A) (tons/yr) 65.4
2. Comparison to selected suspended sediment limits (I.1) - (C) (tons/yr) ± 26.8

WORKSHEET VI.3--continued

J. Changes in sediment transport and/or channel change potential (from introduced sources and direct channel impacts)

1. Total post-silvicultural activity soil mass movement sources (coarse size only) (tons/yr) 146

2. Total post-silvicultural soil mass movement sources (fine or washload only) (tons/yr) 46

3. Particle size (median size of coarse portion) (mm) 10

4. Post-silvicultural activity bedload transport (F) (tons/yr) 1.9

Potential for change (check appropriate blank below)

Stream deposition ✓

Stream scour ____

No change ____

K. Total pre-silvicultural activity potential sediment discharge (bedload + suspended load) (tons/yr) 8.5 (sum A + E)

L. Total post-silvicultural activity potential sediment discharge (all sources + bedload and suspended load) (tons/yr) 220.4 (sum G + H)

M. Potential increase in total sediment discharge due to proposed activity (tons/yr) 211.9 (subtract L - K)

WORKSHEET VI.4

Bedload transport-stream power relationship for Horse Creek, Proposed Plan

(1) Water surface slope S (ft/ft)*	(2) Constant (62.4) K (lb/ft^3)	(3) Measured stream discharge Q (cfs)	(4) Stream width W (ft)	(5) Stream power $\frac{\text{cols. (1)} \times \text{(2)} \times \text{(3)}}{\text{col. (4)}}$ (ft/lb/sec)	(6) Measured bedload transport rate I_b (tons/day)	(7) Convert bedload transport from tons/day to ft/lb/sec, [col. (6) x 2,000] ÷86,400 x col.(4) I_b (ft/lb/sec)
0.0050	62.4	10.5	4.8	0.68	.060	1.39×10^{-3}
0.0050	62.4	3.0	4.2	0.59	.035	0.80×10^{-3}
0.0050	62.4	7.0	3.9	0.56	.025	0.58×10^{-3}
0.0050	62.4	5.0	3.5	0.44	.013	0.30×10^{-3}
0.0050	62.4	4.0	3.1	0.41	.008	0.18×10^{-3}
0.0050	62.4	3.0	2.9	0.32	.004	0.92×10^{-3}
0.0050	62.4	2.0	2.5	0.25	.002	0.46×10

Complete the following analysis:

a. Plot value of stream power (ω), column (5) on X-axis and values of bedload transport rate [I_b, column (7)], on double log graph paper.

b. Calculate regression equation and coefficient of determination (r^2).

* Slope values obtained from adjacent stream - extrapolate data to selected stream. If slope changes calculate new stream power values.

WORKSHEET VI.5

Computations for step 21 Horse Creek
(stream name)
(Proposed Silvicultural Plan)

Changes in bedload transport-stream power due to channel impacts

1. Potential changes in channel dimensions

   a. Bankful stage width (W_{pre}) 1.0 (W_{post}) 1.5

   b. Bankful stage depth (D_{pre}) 0.6 (D_{post}) 0.2

   c. Water surface slope (S_{pre}) 0.029 (S_{post}) 0.0250

   d. Bankful discharge (Q_{Bpre}) 0.73 (Q_{Bpost}) 0.28

where: $Q_{Bpre} = 0.366 + 1.33 \log A_{pre} + 0.05 \log S_{pre} - 0.056 (\log S_{pre})^2$

where: A = cross-sectional area (a) x (b) 0.6

S = water surface slope (c) 0.029

Calculate Q_{Bpost} using post-silvicultural A and S

$$Q_{Bpost} = 0.366 + 1.33 \log A_{post} + 0.05 \log S_{post} - 0.056 (\log S_{post})^2$$

2.a. Pre-silvicultural activity stream power calculation (ω_{pre})

$$\omega_{pre} = \frac{\underset{(1.c)}{S_{pre}} \times \underset{(K)}{62.4} \times \underset{(1.d)}{Q_{Bpre}}}{\underset{(1.a)}{W_{pre}}} = \frac{(.029)(62.4)(.73)}{(1.0)} = 1.32$$

2.b. Post-silvicultural activity stream power calculation (ω_{post})

$$\omega_{post} = \frac{\underset{(1.c)}{S_{post}} \times \underset{(K)}{62.4} \times \underset{(1.d)}{Q_{Bpost}}}{\underset{(1.a)}{W_{post}}} = \frac{(.025)(62.4)(0.28)}{(1.5)} = 0.29$$

3. Calculate post-silvicultural activity bedload transport rate at bankful discharge, using post-silvicultural activity stream power

WORKSHEET VI.3

Sediment prediction worksheet summary

Subdrainage name Horse Creek (Revised Silvicultural Plan) Date of analysis 6/9/78

Suspended Sediment Discharge

A. Pre-silvicultural activity total potential suspended sediment discharge (total col. (4), wksht. VI.1) (tons/yr) 7.1

B. Post-silvicultural activity total potential suspended sediment discharge (total col. (7), wksht. VI.1) (due to streamflow increases) (tons/yr) 8.8

C. Maximum allowable potential suspended sediment discharge (total col. (9), wksht. VI.1) (tons/yr) 38.6

D. Potential introduced sediment sources: (delivered)

1. Surface erosion (tons/yr) 9.8
2. Soil mass movement (coarse) (tons/yr) 0
3. Median particle size (mm) –
4. Soil mass movement-- washload (silts and clays) (tons/yr) 0

Bedload Discharge (Due to increased streamflow)

E. Pre-silvicultural activity potential bedload discharge (tons/yr) 1.4

F. Post-silvicultural activity potential bedload discharge (due to increased streamflow) (tons/yr) 1.9

Total Sediment and Stream Channel Changes

G. Sum of post-silvicultural activity suspended sediment + bedload discharge (other than introduced sources) (tons/yr) 10.7 (sum B + F)

H. Sum of total introduced sediment (D) = (D.1 + D.2 + D.4) (tons/yr) 9.8

I. Total increases in potential suspended sediment discharge

1. (B + D.1 + D.4) - (A) (tons/yr) 11.5
2. Comparison to selected suspended sediment limits (I.1) - (C) (tons/yr) ± 27.1

WORKSHEET VI.3--continued

J. Changes in sediment transport and/or channel change potential (from introduced sources and direct channel impacts)

1. Total post-silvicultural activity soil mass movement sources (coarse size only) (tons/yr) 0
2. Total post-silvicultural soil mass movement sources (fine or washload only) (tons/yr) 0
3. Particle size (median size of coarse portion) (mm) —
4. Post-silvicultural activity bedload transport (F) (tons/yr) 1.9

Potential for change (check appropriate blank below)

Stream deposition ____
Stream scour ____
No change ✓

K. Total pre-silvicultural activity potential sediment discharge (bedload + suspended load) (tons/yr) 8.5 (sum A + E)

L. Total post-silvicultural activity potential sediment discharge (all sources + bedload and suspended load) (tons/yr) 20.5 (sum G + H)

M. Potential increase in total sediment discharge due to proposed activity (tons/yr) 12.0 (subtract L - K)

WORKSHEET VII.1

Variation of solar azimuth and angle with time of day

Time of day (Daylight savings time)	Solar azimuth	Stream1/ effective width (EW) (ft)	Solar angle	Shadow2/ length (S) (ft)
9:00	100°	4.4	30	138.6
10:00	111	4.1	43	85.8
11:00	127	4.0	54	58.1
11:30	135	4.1	58	50.0
12:00	148	4.4	62	42.5
12:30	161	4.9	65	37.3
1:00	180	7.0	65	37.3
1:30	199	14.5	65	37.3
2:00	212	16.4	62	42.5
2:15	215	—	60	46.2
2:30	225	23.0	58	50.0
3:00	233	12.9	54	58.1
4:00	249	7.2	43	85.8
5:00	260	5.6	30	138.6

1/ $EW = \frac{\text{measured average stream width}}{\text{sine} \mid \text{azimuth stream} - \text{azimuth sun}}$

2/ $S = \frac{\text{height vegetation}}{\text{tangent solar angle}}$

WORKSHEET VII.2

Evaluation of downstream temperature impacts

	Stream reach	$A_{adjusted}$ ft²	$H_{adjusted}$ BTU/ft²-min	Q		ΔT 1/ °F	T 2/ °F
				Surface cfs	Subsurface cfs		
1.	Area 27	850	4.31	0.4	—	2.5	57.5
2.							
3.	Area 28	565	4.12	0.3	—	2.1	57.3
4.	(Below confluence)						
5.	Area 29	741	3.94	0.4	—	1.9	56.9
6.							
7.	Area 30						57.2
8.	(Below confluence)						

1/ $\Delta T = \frac{A_{adjusted} \times H_{adjusted}}{Q} \times 0.000267$ where Q is surface flow only.

2/ T from mixing ratio equation.

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Chapter IX

DISSOLVED OXYGEN AND ORGANIC MATTER

this chapter was prepared by the following individuals:

Stanley L. Ponce
John B. Currier

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INTRODUCTION

The dissolved oxygen (DO) concentration in small, forest streams strongly influences the character and productivity of the aquatic ecosystem. Fish and other aquatic organisms need dissolved oxygen to survive, grow, and develop.

Silvicultural activities may influence the dissolved oxygen concentration of a stream draining a logged area. If timber harvesting exposes the stream to direct solar radiation, the water temperature will increase, as discussed in chapter VII, resulting in a decrease in the saturation concentration of DO in the water. In addition, if large quantities of organic debris are allowed to enter and remain in the stream channel over an extended period, they may contribute to decreased DO levels by: (1) forming debris ponds, which enhance heating of water and reduce the reaeration rate; (2) releasing dissolved materials, such as sugars, nutrients, and phenolics, which are readily oxidized by microorganisms; and (3) forming a benthic mat that can inhibit the flow of DO into the intragravel water.

It is not possible to accurately predict the impact of silvicultural activities on the DO concentration of forest streams. The physicochemical properties of oxygen solubility, the pool and riffle nature of mountain streams, and the non-point source pollutants affecting DO concentration make such prediction very difficult. However, several mathematical models have been proposed for use with forest streams. In general, these models are merely extensions of methods developed for quiescent waters, such as rivers and lakes, and most have met with only limited success. One notable exception is a model by Berry (1975) specifically developed to predict the impact of logging debris on dissolved oxygen content in small forest streams. This model can be used to predict DO concentrations in the surface water of a stream where DO content has a critical bearing on a resource management decision. However, if only a rough estimate of the DO concentration in the surface water is required, the Streeter and Phelps (1925) DO sag method may be used. Little work has been done concerning oxygen dynamics in the intragravel zone of a stream. As a result, there are no models available to predict DO changes in the streambed gravels following logging.

Although accurate prediction may not be possible, a clear understanding of oxygen dynamics in a stream is essential to identify silvicultural activities that will adversely affect the DO concentration in a small forest stream. As a result, information on oxygen solubility, the dissolved oxygen balance, dissolved oxygen and logging, and land use practices to protect and maintain the oxygen concentration in a forest stream is explained prior to discussion of the Streeter-Phelps model. Evaluation of the impacts of silvicultural activities on DO concentrations is essential in identifying potential impacts on the fishery resource of a DO reduction caused by timber harvesting.

DISCUSSION

OXYGEN SOLUBILITY IN FRESH WATER

Although free oxygen is abundant in the atmosphere (20.9 percent by weight), it is relatively insoluble in water. The saturation concentration varies between 14.6 mg/l (ppm)[1] at 32° F (0° C) to 7.6 mg/l at 86° F (30° C) under 29.92 inches of Mercury (760 mm) atmospheric pressure. In fresh water, oxygen solubility, or saturation concentration, is determined by atmospheric pressure and the temperature of water. Figure IX.1 illustrates the relationship between temperature, pressure (elevation), and concentration of dissolved oxygen.

Atmospheric pressure. — The effect of pressure is described by Henry's law, which states that the solubility of a gas in a liquid is directly proportional to the pressure of the gas above the liquid. As the atmospheric pressure (partial pressure of oxygen) increases, there is a proportional increase in the water's capacity to hold oxygen. The pressure effect can be calculated by equation IX.1:

$$S^*_{(P)} = S\frac{P-p}{760-p} \qquad \text{(IX.1)}$$

where:

$S^*_{(P)}$ = the oxygen solubility in mg/l at atmospheric pressure P in inches (mm) of mercury,

S = the oxygen solubility at 29.92 inches (760 mm) of mercury, and

p = the pressure (inches or mm) of saturated water vapor at the temperature of the water (American Public Health Association, Inc. 1971).

At elevations below 3,000 feet (900 m) m.s.l. and temperatures below 77° F (25° C), p can be considered negligible. If the elevation (E in feet) is known, an approximate value of P can be calculated by:

$$P = 29.92 / \mathit{exp}\ (E/25{,}000) \qquad \text{(IX.2.)}$$

Water temperature. — The solubility of oxygen in water is inversely proportional to water temperature. This is important because some silvicultural activities expose the stream to direct solar radiation, resulting in an increase in the stream water temperature (chapter VII). As the water temperature increases, its capacity to hold oxygen decreases. The temperature effect can be calculated by:

$$S_{(T)} = 14.56 - 0.38163T + 0.0066366T^2 - 0.00005227T^3 \qquad \text{(IX.3)}$$

where:

$S_{(T)}$ = the solubility of oxygen (mg/l) in water of a given temperature, and

T = the temperature in °C.

IMPORTANCE OF DISSOLVED OXYGEN TO FISH

Adequate levels of DO in the surface and intragravel water are essential for survival of fish. An "adequate level" of DO is a vague term and varies with the species and age of the fish, prior acclimatization, temperature of the water, and concentration of other substances in the water (McKee and Wolf 1963). However, fishery biologists often use the following "rule of thumb" for minimum DO concentrations for freshwater biota: 5 mg/l for warm water species, declining to a lower limit of 4 mg/l for short periods, provided that the water quality is favorable in all other respects; and no less than 6 mg/l, or 7 mg/l during spawning times, for cold water species.

Fish often are exposed to DO concentrations well below 5 mg/l for prolonged periods. DO concentrations between 5 and 2.5 mg/l are generally considered sublethal to fish. Under such conditions, fish experience an oxygen stress, and if the exposure is extended, their activity, growth, and reproduction may be reduced.

Several responses to oxygen deficiencies by fish within the surface water and by fish eggs and embryos in the intragravel water have been reported. Shellford and Allee (1913) studied the avoidance reaction of 16 species of fish to different

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[1] *In fresh water (total dissolved solids <7,000 mg/l) 1 mg/l = 1 ppm (Hem 1970). As a result, the English unit of concentration will not be given throughout the balance of this chapter since it is equivalent to the mg/l of concentration.*

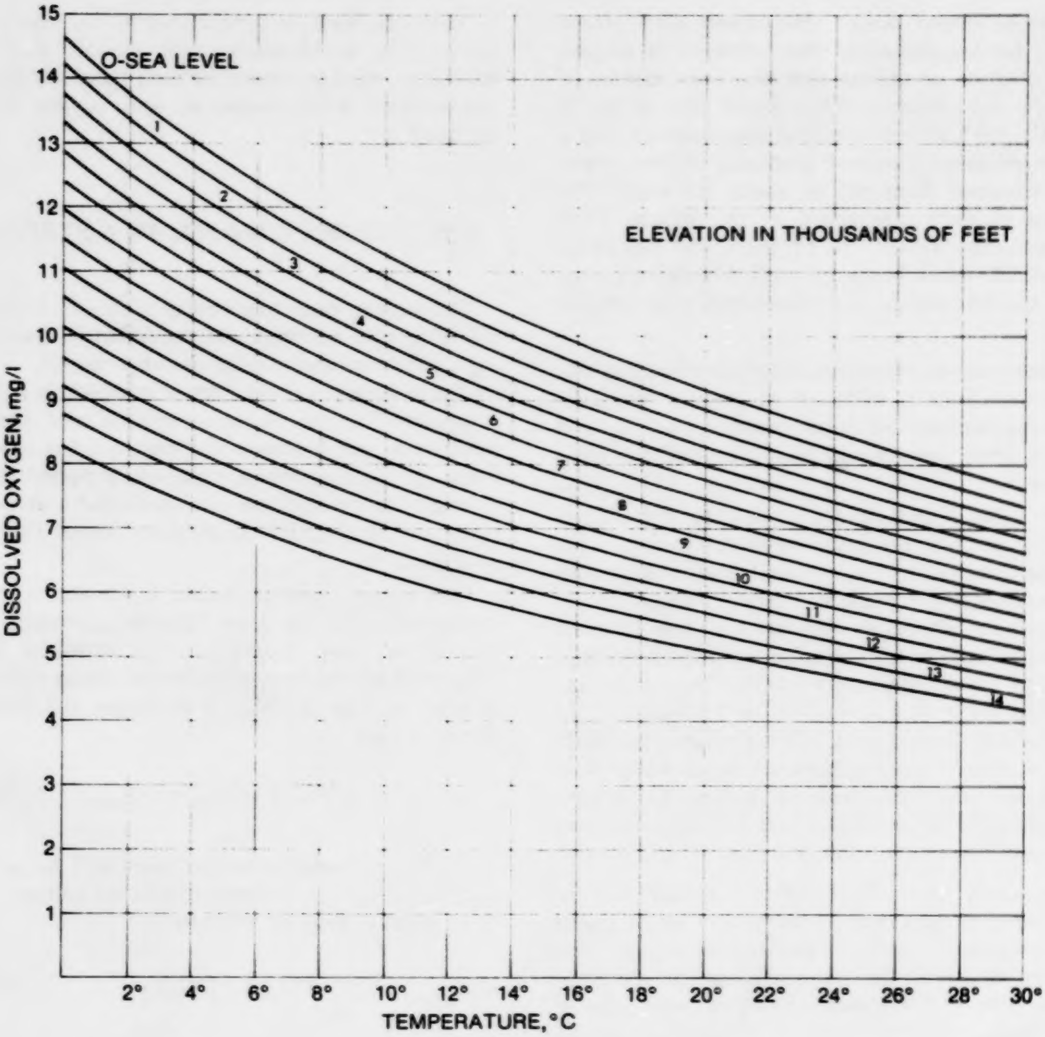


Figure IX.1.—Relationship between temperature, pressure (elevation), and dissolved oxygen.

concentrations of oxygen. They reported a definite effort by all the fish to avoid water substantially deficient in oxygen. Jones (1952) ran a similar experiment with stickleback, minnows, and trout fry. At temperatures near 68° F (20° C), all three species reacted violently and retreated rapidly when they swam into water containing 0.5 to 1.0 mg/l of DO. At a concentration of 3.5 mg/l, the reaction was again one of rejection but much slower. Whitmore and others (1960) conducted avoidance tests with juvenile chinook and coho salmon, large mouth bass, and bluegill. They found all four species markedly avoided water containing less than 4.5 mg/l of DO; some coho avoided concentrations of 6 mg/l.

Davison and others (1959), studying dissolved oxygen requirements of cold water fishes, reported that at a temperature of 64° F (18° C), young coho salmon survived for 30 days at a DO level of 2.0 mg/l. During this period the fish ate little and lost weight. At a higher DO level, near 3.0 mg/l, the fish ate more food and gained weight. However, this gain was much less than that of similar fish in oxygen-saturated water. Herrmann and others (1962) further examined the influence of oxygen concentration on growth and food consumption of juvenile coho salmon. They found that at 68° F (20° C), both growth and food consumption over a prolonged period declined gradually as the oxygen level dropped from 8.3 to about 5.5 mg/l. The decline of each was rapid as the oxygen level dropped from about 5 to 1.8 mg/l, and fish often died at DO levels below 1.0 mg/l. The fish ate very little and lost weight at oxygen levels at or below 2 mg/l.

These studies indicate that fish attempt to avoid areas significantly deficient in oxygen, and that when fish are exposed to such water for a prolonged period, their growth and food consumption rates decrease.

The value of high oxygen levels in the intragravel water is often overlooked. However, it is critical for Pacific Coast salmonoids, as well as other sport and commercial fish that spawn in small forest streams. The salmonoid species deposit their eggs 10 to 12 inches (25 to 30 cm) deep into the stream gravels. The eggs hatch, and the embryos develop for approximately 3 months before the fry emerge into the surface water (Lantz 1971). Continuously high oxygen levels during embryo development are very important. If oxygen becomes deficient, the percent egg survival, rate of embryo development, and quality of fish produced may decrease significantly.

Shumway and others (1964) examined the influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. In their experiment, embryos raised from fertilization to hatching were exposed to different concentrations of DO ranging from 2.5 to 11.5 mg/l and water velocities ranging from 2 to 138 in/hr (3 to 350 cm/hr) under a near constant temperature of 50° F (10° C). They found that fry produced from embryos raised at oxygen levels of less than 4.0 mg/l hatched later and were smaller at hatching than fry from embryos raised at oxygen levels near saturation. They also reported that reduced water velocities affected the fry in much the same manner as reduced oxygen levels, although the effect was not as pronounced.

Garside (1966) conducted a similar experiment which examined the effects of oxygen and temperature on brook and rainbow trout embryo development. The embryos of each species were exposed to oxygen concentrations of 2.5, 3.5, and 10 mg/l at each of four temperatures — 36° F (2.5° C), 41° F (5.0° C), 45° F (7.5° C), and 50° F (10° C) — from the time of fertilization to late development. The development rate slowed and the hatching period increased for both species of fish as temperature levels increased and oxygen levels declined.

THE OXYGEN BALANCE IN A STREAM

The oxygen concentration in a stream is determined by the addition and depletion of dissolved oxygen by biological and physical processes. Under undisturbed conditions, a forest stream is in a state of oxygen balance. Aquatic animals and decomposition agents continuously withdraw free oxygen while, at the same time, oxygen is supplied intermittently by green plants during daylight, and continuously by direct absorption from the atmosphere.

The oxygen system within a stream may be described using the mass balance approach. The change in mass of DO (ΔDO_m) within a fixed volume of stream is equated to the inputs ($DO_{m(i)}$) minus the outputs ($DO_{m(o)}$) of oxygen and may be expressed as:

$$\Delta DO_m = DO_{m(i)} - DO_{m(o)} \qquad \text{(IX.4)}$$

If an oxygen balance exists, there will be no net change in the oxygen mass within the volume, and the equation may be reduced to:

$$DO_{m(i)} = DO_{m(o)} \qquad \text{(IX.5)}$$

The oxygen balance of a section of mountain stream (fig. IX.2) under undisturbed conditions is illustrated diagrammatically in figure IX.3. The size of the arrows between components indicates the magnitude of oxygen transfer.

A mountain stream is replenished with oxygen from three sources: the direct absorption at its surface, the photosynthetic process of green aquatic plants, and, to a minor extent, the influent ground water.

Surface water is supplied with oxygen primarily by direct absorption (reaeration) from the atmosphere. The reaeration rate is a function of the DO concentration at the surface, while the dispersion of oxygen thoughout the water is controlled by simple molecular diffusion and mass transfer. In

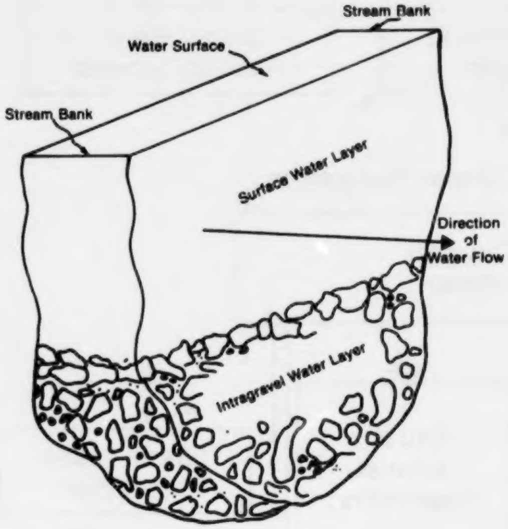


Figure IX.2.—Hypothetical section of stream channel to be considered in the dissolved oxygen mass balance.

general, the rate of reaeration in a still water body, such as a pond or lake, is relatively slow. However, forest streams often have steep gradients that result in turbulence, which produces vertical and horizontal mixing as well as oxygen entrainment, all of which greatly increase the reaeration rate.

During daylight, plankton and algae that are often present in quiet pools photosynthesize and produce free oxygen as a byproduct. In large, low gradient streams or lakes, photosynthesis may serve as a major source of oxygen; however, in small forest streams, it is generally only a very minor source of oxygen (Camp 1965).

The intragravel water is supplied with oxygen primarily by mass transfer and diffusion from the overlying surface water. The rate of this transfer and diffusion is relatively slow, because the mixing agents present in the surface water are inhibited in the intragravel water. Water velocity through the intragravel layer is much lower than the surface layer: 1 to 2 in/hr (2 to 5 cm/ hr) compared to 20 to 60 in/sec (50 to 150 cm/sec) (Narver 1971).

A second, and generally very minor, input of oxygen into the intragravel water is oxygen carried in by influent ground water (Vaux 1968). Sheridan (1962) found that oxygen input by ground water in pink salmon streams in southeast Alaska was very small. He concluded that the major intragravel oxygen source was direct diffusion from the surface layer.

The predominant dissolved oxygen sink in an unpolluted mountain stream, both in the surface and intragravel water, is biochemical oxygen demand (BOD). DO will be lost to a lesser extent to respiration by larger aquatic life and plants, to the atmosphere by direct diffusion — if the stream is in a state of oxygen supersaturation — and to effluent ground water flow.

Biochemical oxygen demand imposes the greatest drain on a stream's DO supply. The BOD process in a mountain stream is illustrated diagrammatically in figure IX.4. The decomposition agents (decomposers) may be separated into two classes: dispersed and attached organisms. Dispersed organisms flow freely within the stream; attached organisms remain stationary, attached to rocks and other fixed objects. Both exert an oxygen demand. In a small forest stream, where the gradient is high and the flow turbulent, dispersed organisms generally predominate. In streams where the gradient is low and there are a number of quiescent pools, attached organisms may exert a significant demand. In general, the decomposers are comprised primarily of bacteria, protozoa, fungi, and, to a lesser extent, larger aquatic life (insects and fish).

The substrate, or food source, is composed of suspended material (finely divided plant material), dissolved material (nutrients and simple sugars leached from plant material), and benthic deposits (organic material that has settled to the stream bottom).

Once the material is ingested, the assimilative process is one of wet oxidation within the decomposers. This process may be expressed by the following reaction:

$$\text{Substrate} + O_2 \xrightarrow{\text{organism}} CO_2 + H_2O \qquad \text{(IX.6)}$$
$$+ \text{ energy} + \text{other byproducts}$$

In this process, the decomposers utilize oxygen to break down the substrate to produce carbon dioxide, water, energy for growth and reproduction, and other byproducts.

Larger aquatic life impose another sink on a stream's dissolved oxygen supply (fig. IX.3). Although a mountain stream may appear to be relatively free of larger aquatic life, it generally supports a multitude of organisms, such as snails,

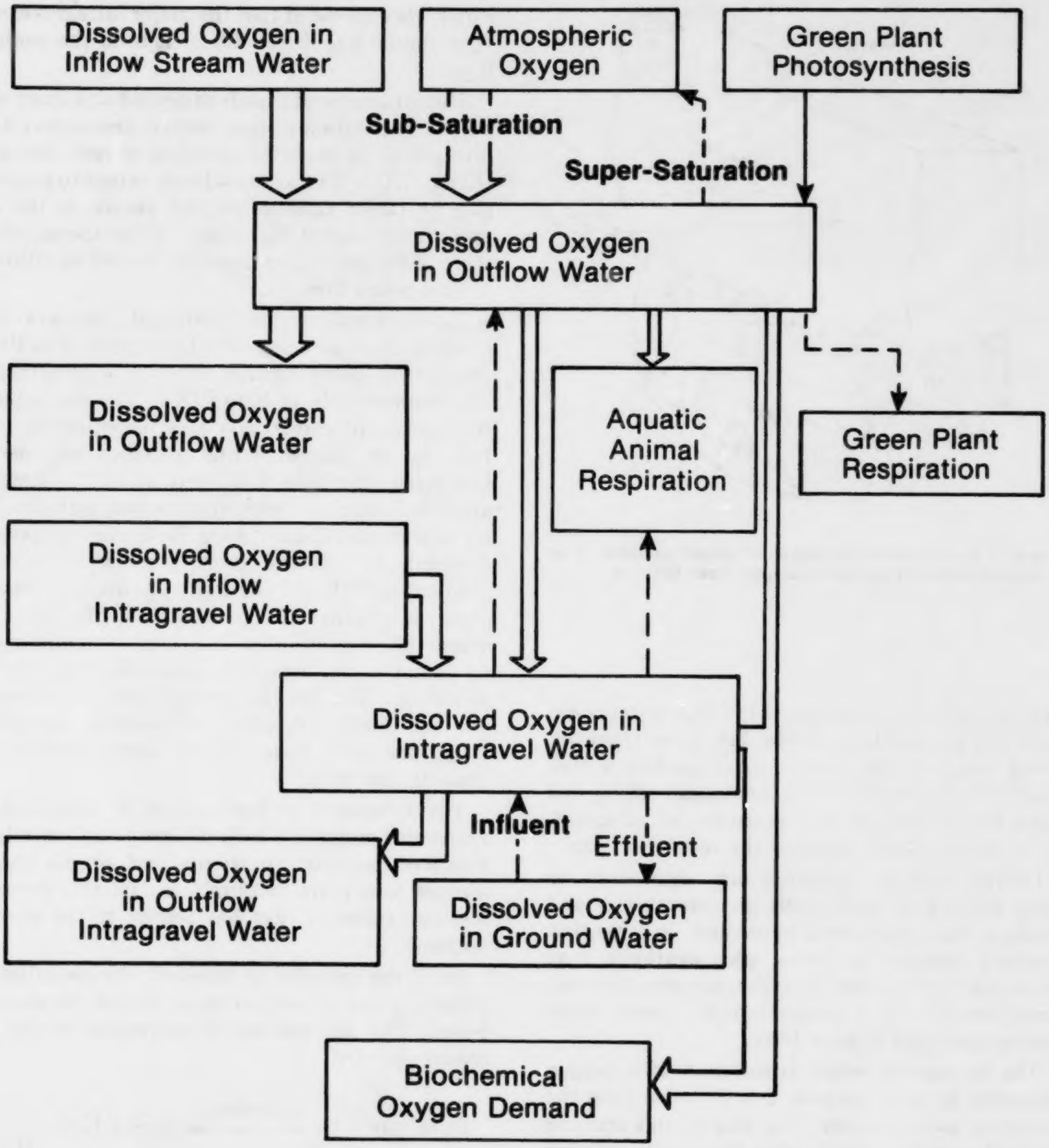
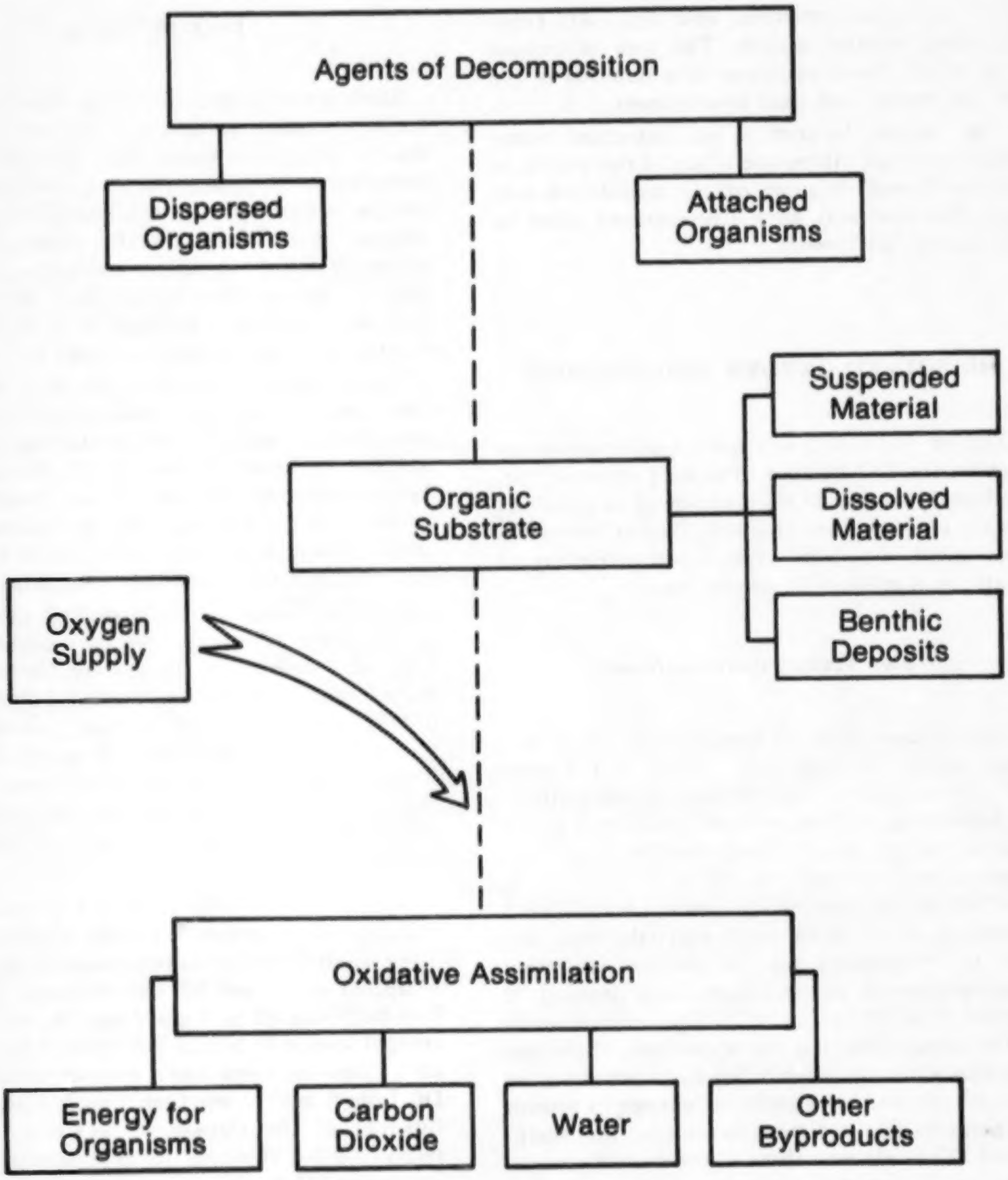

Dissolved Oxygen in Inflow Stream Water
Atmospheric Oxygen
Green Plant Photosynthesis
Sub-Saturation
Super-Saturation
Dissolved Oxygen in Outflow Water
Dissolved Oxygen in Outflow Water
Aquatic Animal Respiration
Green Plant Respiration
Dissolved Oxygen in Inflow Intragravel Water
Dissolved Oxygen in Intragravel Water
Influent
Effluent
Dissolved Oxygen in Outflow Intragravel Water
Dissolved Oxygen in Ground Water
Biochemical Oxygen Demand

Figure IX.3.—Sources and sinks of dissolved oxygen in a mountain stream under undisturbed conditions (Ponce 1974b).



$$\text{Substrate} + O_2 \xrightarrow{\text{organism}} CO_2 + H_2O + \text{energy} + \text{other byproducts}$$

Figure IX.4.—The biochemical oxygen demand process in a mountain stream (Ponce 1974b).

insect nymphs, crayfish, and fish. All these organisms require oxygen. The rate of oxygen removal by these organisms is a function of the species present and their environment.

The oxygen balance is an important water quality concept. Alteration of any of the sources or sinks will result in a new oxygen equilibrium concentration and may have a pronounced effect on the aquatic life present.

DISSOLVED OXYGEN AND LOGGING

Timber harvesting can have a substantial impact on the DO balance in upland streams, particularly if logging debris are allowed to enter and remain in the stream channel. Timber harvesting may affect dissolved oxygen concentrations in small forest streams in several ways.

Water Temperature Increases

Logging may alter the temperature regime in a small stream (chapter VII). Brown and Krygier (1970) evaluated the effect of two different methods of clearcutting on stream temperature in Oregon's Coastal Range. They found that the maximum temperature increased from 57° to 85° F (13.9° to 29.4° C) on the completely clearcut watershed 1 year after cutting. In terms of oxygen decrease, due only to temperature fluctuation, the saturation concentration of oxygen would have dropped 28 percent (from 10.3 to 7.4 mg/l). Temperature levels in the stream draining the watershed, which was patchcut with vegetation buffer strips left along the channel, showed no significant change in stream temperature due to timber harvesting, and maintained DO levels near those of the control stream.

Similar trends have been observed in the Appalachian highlands. Eschner and Larmoyeux (1963) report that, prior to treatment, there was little difference between water temperatures of the control watershed and the watershed to be entirely clearcut. However, the first year following cutting, the maximum water temperature measured on the clearcut watershed was 75° F (23° C), 20° F (11° C) greater than the maximum recorded on the control stream. In terms of DO solubility in the stream, the saturation concentration would have dropped 19 percent (9.0 to 7.3 mg/l).

Logging Debris

Slash is a byproduct of logging. It is composed of limbs, branches, needles, and leaves of trees. This debris, along with forest floor material, may accumulate in the stream channel, particularly if log yarding across the channel is permitted. Once this organic material enters the channel, it may adversely affect the DO concentration in several ways: (1) by exerting a high BOD, (2) by restricting flow and reducing reaeration, and (3) by accentuating water temperature increases.

The oxygen demand (BOD) by plant matter has been well documented. Plant materials contain simple sugars and other nutrients that are readily leached in water (Currier 1974, Ponce 1974b). Microorganisms consume these leached constituents and, in turn, exert a demand on the stream's oxygen supply. This demand for oxygen may continue for a relatively long period.

Chase and Ferullo (1957) studied the effect of autumn leaf fall on the oxygen concentration in lakes and streams in the eastern United States. After 1 year, maple leaves demanded about 750 mg of O_2/g of initial dry weight, while oak leaves and pine needles required about 125 mg of O_2/g of initial dry weight. The oxygen uptake was relatively rapid: by day 100 maple had achieved about 70 percent, and oak and pine 55 percent, of the demand exerted in 1 year.

Slack and Feltz (1968) examined the effect of leaf fall on quality changes in a small Virginia stream. They reported no significant change in oxygen consumption as the leaf fall rate increased from 0 to 0.05 lb/ft^2/day (0 to 2 g/m^2/day). As the rate increased from 0.05 to 0.28 lb/ft^2/day (2 to 12 g/m^2/day), however, there was a corresponding drop in DO from 8 mg/l to less than 1 mg/l. Upon natural flushing of the stream by a storm, the DO responded by climbing to near saturation concentration (11 mg/l).

Ponce (1974a) determined the BOD of Douglas-fir needles and twigs, western hemlock needles, and red alder leaves in stream water. The oxygen demand by these materials was measured for 90 days at 68° F (20° C) and for 5 days under the condition of temperature fluctuation similar to patterns observed in clearcut watersheds of the Oregon Coastal Range. Selected results of Ponce's work are presented in tables IX.1 and IX.2. It is apparent that this material exerts a substantial oxygen demand: 101, 178, and 273 mg of O_2/g for Douglas-fir,

Table IX.1.—Mean[1] cumulative BOD in milligrams of O_2/g (dry weight) by Douglas-fir needles and twigs, western hemlock needles, and red alder leaves in stream water at 20° C (Ponce 1974a)

Vegetation type	Days 5	10	20	45	60	90
	milligrams of O_2/g					
Douglas-fir needles	63	76	97	99	96	101
Western hemlock needles	32	88	130	169	176	178
Red alder leaves	79	124	169	239	260	273
Douglas-fir twigs	25	47	75	100	---	---

[1]The mean of four replications for each species

Table IX.2.—Mean[1] cumulative BOD in milligrams of O_2/g (dry weight) by Douglas-fir, western hemlock, and red alder leaves under conditions of temperature fluctuation (Ponce 1974a)

Vegetation type	Days 1	2	3	4	5
	milligrams of O_2/g				
Douglas-fir needles	46	62	124	175	190
Western hemlock needles	24	55	81	92	97
Red alder leaves	72	131	124	207	237

[1]The mean of three replications for each species.

western hemlock, and red alder leaves, respectively, over 90 days; and 100 mg of O_2/g for Douglas-fir twigs over 45 days at 20° C. This demand is exerted relatively rapidly with 96, 73, and 62 percent of the 90-day demand achieved in 20 days for Douglas-fir, western hemlock, and red alder leaves, respectively. When the temperature fluctuated, the oxygen demand increased by a factor of 3 for each leaf type over the 5-day test period.

The toxicity of the leachate extracted from each of these vegetative species was determined on guppies and steelhead trout fry. The concentration of leachate needed to produce toxic effects was so high that oxygen depletion probably would be responsible for death long before the leachate effect would.

Hall and Lantz (1969) reported the effects of logging on habitat of coho salmon and cutthroat trout in coastal streams of Oregon. Two small watersheds were studied, one completely clearcut, the other patchcut with buffer strips. They were compared with a third watershed that served as a control. Felling on the clearcut watershed began in the spring. Timber was felled along the stream, and logs were yarded uphill by cable across the stream to landings. This resulted in the accumulation of considerable quantity of debris in the channel, which restricted flow and formed pools. The large material remained in the channel throughout the summer. In early fall, the channel was cleared of the large material to permit free flow.

DO concentration was substantially reduced in surface and intragravel waters of the clearcut watershed (figs. IX.5 and IX.6). The DO reduction was noted first in the intragravel water, after felling began along the stream. A layer of debris on the gravel and ponding of the surface water caused a substantial decrease in the rate of oxygen transfer from the surface to the intragravel water. This decrease, coupled with an oxygen demand by the decomposing debris, caused a rapid decline in DO in the intragravel water. DO concentrations in the surface water from late spring through most of the summer were too low to support salmon and trout in one-third of the streams available to the salmonoids; juvenile coho salmon placed in live-boxes there survived less than 40 minutes. The lowest oxygen concentration reported, 0.6 mg/l, was observed in a pool resulting from a dam composed of debris. During this period, oxygen concentration of the control stream and the stream

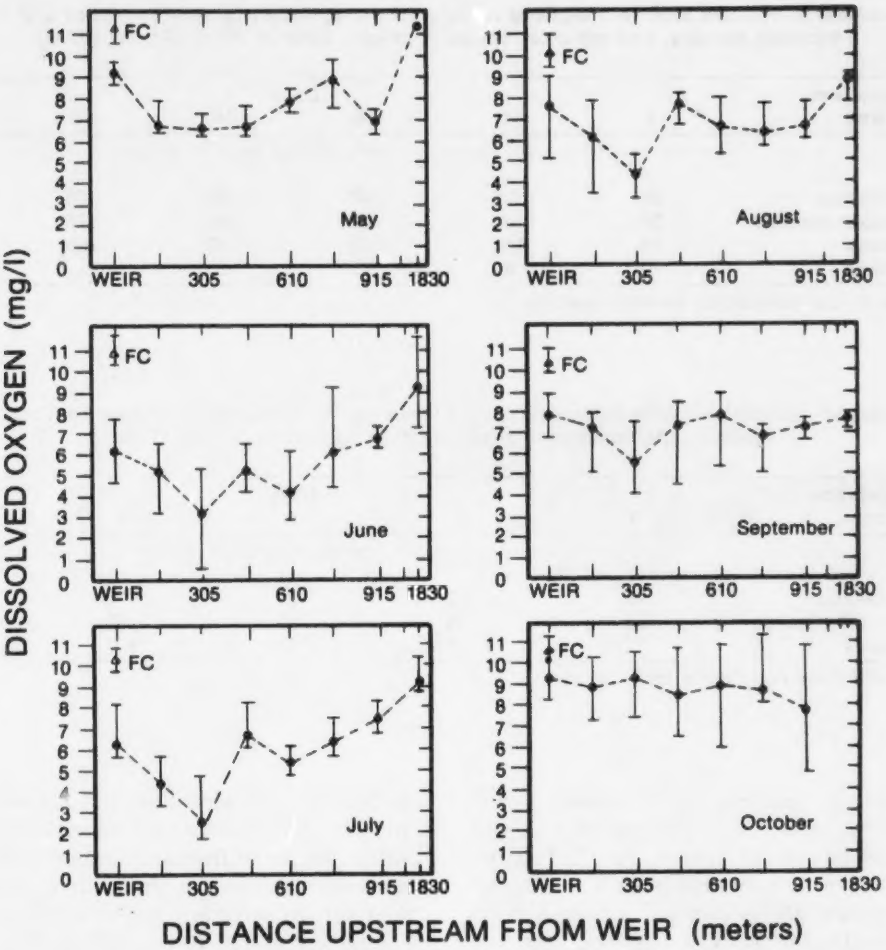


Figure IX.5.—Surface dissolved oxygen levels (mean and range) taken twice weekly in the clearcut watershed (Needle Branch) and control watershed (Flynn Creek) during the year of timber harvest (1966). Sampling on Needle Branch occurred at 500 feet (152 m) in the area accessible to salmon and 6,004 feet (1,830 m) (upper edge of clearcut). Samples from Flynn Creek were taken only at the weir (Hall and Lantz 1969).

draining the patchcut watershed remained at near saturation levels. Upon removal of large debris from the channel and establishment of free-flowing conditions, the DO concentration rapidly returned to near pre-logging conditions in the surface water. Intragravel oxygen concentrations, however, remained about 3.0 mg/l lower than the pre-logging concentrations for the next 2 years, and continued to decline over the next 4 years to levels less than 2.0 mg/l at several locations.

Although a portion of the intragravel DO decline was attributed to long-term BOD by organic matter that intruded the gravel, it was concluded the major cause for the prolonged reduction was restriction of water flow through the gravel due to sedimentation in the gravel bed. Garvin (1974) found that, in the absence of sedimentation, logging debris intrusion into streambeds resulted in a large, but short-term, reduction of DO concentration in the gravel. Within 6 months, DO levels returned to almost normal.

It is apparent that logging debris may be responsible for severe oxygen deficits within small forest streams. However, it should be noted that the pollution impact of this material, particularly the finely divided debris, depends not only on the amount that enters the stream, but also the season it enters the stream. Debris deposited in an Oregon Coastal Range stream between early fall and late winter generally caused only minor oxygen deficit. During this period, winter freshets provide the streams the energy to flush the material through the system. However, if the material is deposited between early spring and late summer, serious oxygen deficit is much more likely. During this period, the streams are generally at low flow and do not have sufficient energy to transport the debris.

PREDICTING DISSOLVED OXYGEN DEFICITS, THE DO SAG METHOD

Berry (1975) developed a working computer model to predict the impact of logging debris on dissolved oxygen concentrations in small forest streams. Since this model appears to yield reliable results, it can be used to predict DO concentration

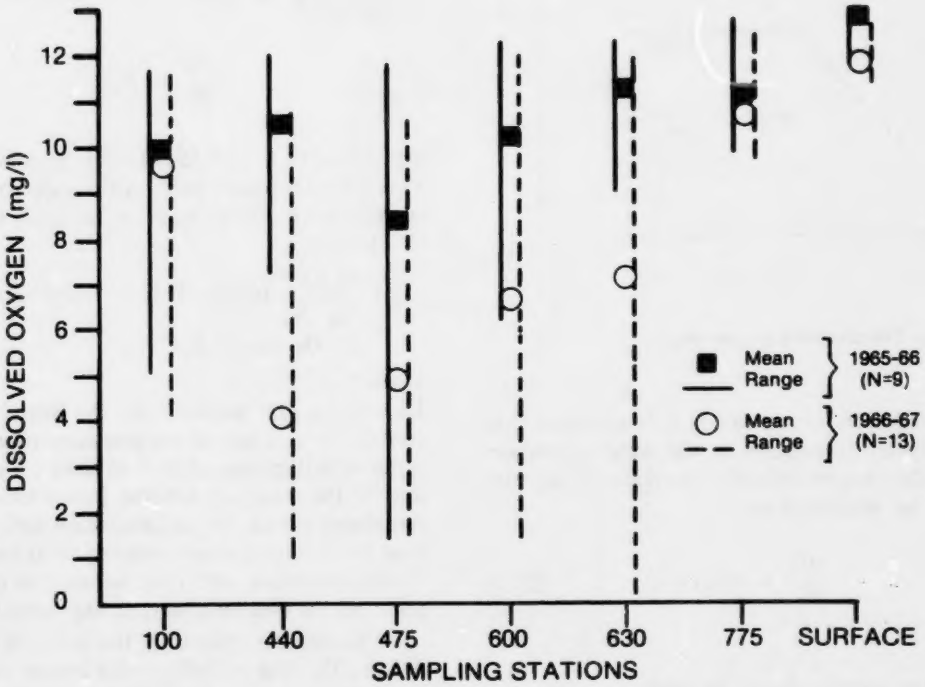


Figure IX.6.—Intragravel dissolved oxygen levels in the clearcut watershed (Needle Branch) from December 1965 to May 1966 (before logging). (All standpipes in Needle Branch were removed during logging; the six for which data are shown were replaced in their previous locations). Surface dissolved oxygen levels are shown for comparison (Hall and Lantz 1969).

for resource management decisions. However, if only a coarse estimate of the oxygen deficiency is required, it may be obtained by using the DO sag method developed by Streeter and Phelps (1925). The numerous limitations associated with this method that greatly affect the accuracy of the prediction will be noted later.

The DO sag concept is illustrated in figure IX.7. It is assumed that the rate change in oxygen deficit is governed by two independent reactions which occur simultaneously: reaeration and biochemical oxygen demand (depletion). Each of these processes, in turn, may be described by a differential equation.

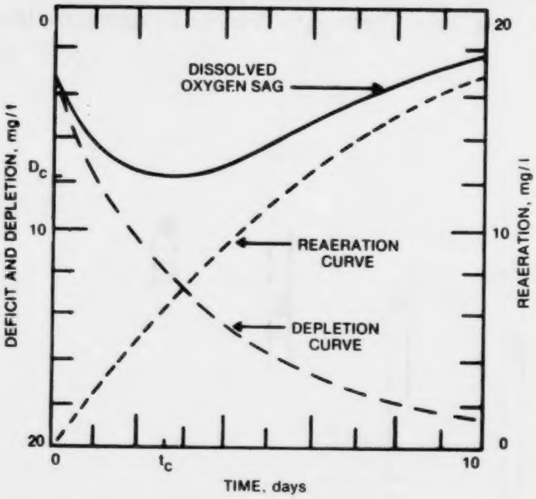


Figure IX.7—The dissolved oxygen sag.

In the reaeratation equation, it is assumed that rate of oxygen absorption by the water is proportional to the oxygen deficit in the water. This relation may be expressed as:

$$\frac{dD}{dt} = -K_2D \qquad \text{(IX.7)}$$

where:

D = the oxygen deficit in mg/l
t = time in days, and
K_2 = is the reaeration constant (base e) in units of l/day.

In the depletion equation, it is assumed that the rate of biochemical oxygen demand (BOD) due to biochemical oxidation is proportional to the amount of BOD present. This may be expressed as:

$$\frac{dL}{dt} = -K_1L \qquad \text{(IX.8)}$$

where:

L = the BOD concentration in mg of O_2/g,
K_1 = the BOD rate coefficient (base e) in units of l/day, and
t = is as previously defined.

Equation IX.8 also may be expressed in terms of oxygen deficit, D. Since BOD concentration is measured in terms of the quantity of oxygen consumed, it follows that the rate change in BOD is equal to the rate of oxygen depletion. The rate of oxygen depletion may be expressed as the rate change in oxygen deficit:

$$-\frac{dL}{dt} = \frac{dD}{dt} \qquad \text{(IX.9)}$$

Substituting equation IX.8 in IX.9 yields equation IX.10:

$$\frac{dD}{dt} = K_1L \qquad \text{(IX.10)}$$

Equations IX.7 and IX.10 may be combined and solved for D, which enables the calculation of oxygen deficit at any given time, resulting in equation IX.11:

$$D = \frac{K_1La}{K_2-K_1}\left[exp\ (-K_1t) - exp\ (-K_2t)\right] + Da\ exp\ (-K_2t) \qquad \text{(IX.11)}$$

where:
La and Da are, respectively, the initial BOD concentration and initial oxygen saturation deficit in units of milligrams of O_2/l at time (t) equal to O, *exp* is the base of natural logarithms, and the remaining terms are as previously defined. Equation IX.11 is commonly referred to as the Streeter-Phelps equation, and may be used to predict any point on the dissolved oxygen sag curve (fig. IX.7).

Of particular interest is the point of maximum deficit, D_c (mg of O_2/l) — the lowest point in the DO sag curve — and the time it occurs, t_c (days). The point of maximum deficit may be calculated by equation IX.12 developed by Fair (1939):

$$D_c = \frac{K_1}{K_2}La\ exp\ (-K_1t_c) \qquad \text{(IX.12)}$$

The critical time, t_c, is obtained from equation IX.13 developed by Fair (1939):

$$t_c = \frac{K_1}{K_2 - K_1} \ln \frac{K_2}{L_1} \left[1 - \frac{Da\,(K_2 - K_1)}{K_1 La} \right] \qquad \text{(IX.13)}$$

All terms in equations IX.12 and IX.13 are as previously defined.

Predicting Components Of The DO Sag Method

Although the DO sag method appears to be simple to apply, it is difficult to obtain reliable results because of the lack of accurate values for K_1, K_2, and La. Berry (1975) suggests the following equations to predict these components.

The reaeration rate constant. — The reaeration rate constant can be predicted with equation IX.14 developed by Holtje (1971):

$$K_{2(T)} = 1.016^{(T-20)}[181.6\,E - 1657\,S + 20.87] \qquad \text{(IX.14)}$$

where:

$K_{2(T)}$ = the reaeration rate constant (l/day) at the water temperature T (°C),

E = energy of dissipation (ft^2/sec^3 or m^2/sec^3), and

S = the average channel slope (ft/ft or m/m).

The energy of dissipation can be calculated by:

$$E = (S)(U)(g) \qquad \text{(IX.15)}$$

where:

U = the average velocity (ft/sec or m/sec), and

g = the gravitational acceleration constant (32.2 ft/sec^2 or 980 cm/sec^2).

The leachate BOD rate constant. — The leachate BOD rate constant, $K_{1(T)}$ (liter/day), can be determined by the set of equations developed by Zanoni (1967):

$$K_{1(T)} = 0.796\,[1.126^{(T-20)} K_{1(20)}]; \quad 2° \le T < 15° \text{ C} \qquad \text{(IX.16)}$$

$$K_{1(T)} = 1.000\,[1.047^{(T-20)} K_{1(20)}]; \quad 15° \le T < 32° \text{ C} \qquad \text{(IX.17)}$$

$$K_{1(T)} = 1.728\,[0.985^{(T-20)} K_{1(20)}]; \quad 32° \le T < 40° \text{ C} \qquad \text{(IX.18)}$$

where:

$K_{1(T)}$ and $K_{1(20)}$ are values of the reaeration rate constant in liter/day at water temperature T and 20° C, respectively. Values of $K_{1(20)}$ for various types of organic matter can be obtained from table IX.3.

The leachate concentration. — The leachate concentration, $La_{(T)}$ (mg/l), may be determined by equation IX.19 or IX.20 developed by Zanoni (1967):

$$La_{(T)} = La_{(20)}[1.0 + 0.0033(T-20)]; \quad 2° \le T < 20° \text{ C} \qquad \text{(IX.19)}$$

$$La_{(T)} = La_{(20)}[1.0 + 0.0113(T-20)]; \quad 20° \le T < 35° \text{ C} \qquad \text{(IX.20)}$$

where:

$La_{(T)}$ and $La_{(20)}$ are the leachate BOD concentration milligrams of O_2/g at water temperature T and 20° C, respectively. Values of $La_{(20)}$ for various types of organic matter can be obtained from table IX.3.

Table IX.3—$K_{1(20)}$ and $La_{(20)}$ values for selected tree species and materials

Vegetation type	$K_{1(20)}$ (liter/day)	$La_{(20)}$ O_2 of (mg/g)	Reference
	liter/day	milligrams of O_2/g	
Douglas-fir needles	0.125	[1]110	Ponce (1974a)
Douglas-fir twigs	0.056	[2]110	Ponce (1974a)
Western hemlock needles	0.640	[1]166	Ponce (1974a)
Red alder leaves	0.047	[1]286	Ponce (1974a)
Maple leaves[3]	[4]0.006	[1]525	Chase and Ferullo (1957)
Pine needles[3]	[4]0.005	[1] 68	Chase and Ferullo (1957)
Oak leaves[3]	[4]0.006	[1] 80	Chase and Ferullo (1957)

[1] Ninety-day ultimate demand.

[2] Forty-five-day ultimate demand.

[3] Species not given.

[4] Represent $K_{1(25)}$ values.

APPLICATIONS, LIMITATIONS, AND PRECAUTIONS

The applications of the DO sag method have been discussed earlier. However, the method has several important limiting factors. The oxygen sag method does not account for the following:

1. The continuous redistribution of both the BOD and oxygen by the effect of longitudinal dispersion.
2. Changes in channel configuration that alter the characteristics of surface turbulence and the reaeration rate, K_2.
3. Diurnal variation in oxygen content and water temperature.
4. The variation of K_1 over time.
5. The removal of oxygen from the water by diffusion into the intragravel layer.
6. The addition of BOD below the point of reference.
7. The effect of suspended and dissolved substances on the rate of diffusion of oxygen from the surface into the main body of the stream.
8. Nitrogenous BOD (the method assumes nitrogenous BOD does not occur).
9. Ponding.

CONCLUSIONS

Changes in dissolved oxygen concentration in streams resulting from silvicultural activities usually can be linked to changes in stream temperature and introduced organic debris. Control practices and abatement goals that meet temperature and sediment standards will also minimize the reduction of dissolved oxygen.

Introduced organic matter may contribute additional stress on dissolved oxygen concentration beyond that produced by increased water temperature. Primarily, the magnitude of the impact of organic matter on dissolved oxygen increases with:

1. The amount and type of organic debris entering the stream either directly or indirectly through runoff;
2. The extent to which the debris dams the stream course and produces pools, thus facilitating heating and reduction of reaeration; and
3. The length of time the debris remains in the stream water.

Steep slopes near the stream channel increase the probability of debris washoff, and a decrease in the stream channel gradient reduces the rate of reaeration.

Introduction of solid organic debris during silvicultural activities can be minimized or eliminated. Finer organic particles normally will enter a stream along with the surface eroded materials. For organic material to enter the stream via surface erosion in sufficient quantity to adversely affect the aquatic ecosystem, the quantity of eroded soils would have to be so large that it would present a problem in itself, overshadowing any deterioration of water quality due to the organic matter component.

Large debris can be prevented from entering the stream by felling trees away from the stream, by avoiding the stream in all skidding operations, and/or by leaving an adequate streamside zone. Froehlich (1976) found accelerated debris loading through logging to be most strongly related to the timber felling process. Conventional felling resulted in a fivefold increase in organic loading, whereas directional felling only doubled the load. Streamside zones provided a debris barrier that limited or totally prevented the loading increase, with effectiveness in restricting organic loading varying with width of the area.

Large debris deposited in a stream during a silvicultural activity normally should be removed as soon as possible. However, some large debris within a watercourse can provide stable and diverse habitats for biota. Removal of debris that have been in position for any extended period and have trapped considerable sediment normally should not be undertaken until the full impact (loss of habitat, increased turbidity, realignment of stream, etc.) is evaluated. A general policy for removal of all debris in a stream is unreasonable and could result in damage to water quality and aquatic habitat (Triska and Sedell 1977).

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Chapter X

NUTRIENTS

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INTRODUCTION

Much concern has been expressed over nutrient additions to streams following silvicultural activities. Of the nutrients, nitrogen and phosphorus generally have the greatest impact upon water quality. Introduction of nitrogen and phosphorus to forest streams may result in enrichment of the receiving waters (i.e., eutrophication), as these two chemicals are normally limiting factors in the production of aquatic vegetation. Accelerated additions of nutrients to streams following silvicultural activities may result in accelerated eutrophication and adversely affect stream water quality. In other cases, however, enrichment of streams may be beneficial, particularly in streams relatively devoid of dissolved nutrients in their natural state.

Streams may show symptoms of overenrichment; however, there is usually minimal opportunity for a buildup of these nutrients in the stream system because of the continual transport of water and the normally brief period of increased nutrient influx to the stream. Other nutrients rarely cause water quality problems. This discussion, therefore, is limited to nitrogen and phosphorus. (For additional information on the nutrient cycle, see appendix X.A.)

Research conducted throughout the United States and Canada has found that nutrient outflux following silvicultural activity usually does not result in any measurable deterioration of water quality. The most notable exception is the Hubbard Brook experimental watershed in New Hampshire. This was, however, an extreme experimental treatment and not a normal silvicultural activity. Based upon existing research, it can be concluded that nutrient release associated with silvicultural activities may occur; but resulting concentrations of nitrogen and phosphorus will normally not be great enough to adversely affect the water quality of the receiving forest streams.

Quantification of nitrogen and phosphorus influx into a watercourse, given a specific site and proposed silvicultural activity, is not possible at this time. There are no available models capable of accurately predicting the total nutrient addition to streams due to silvicultural activities. The soluble component of the nutrient outflux can be examined presently only through a comparison of those nutrients contributed by silvicultural activities with those nutrients contributed by other land management practices. The insoluble component can be estimated with cautious use of one available model.

DISCUSSION

SOLUBLE COMPONENT EVALUATION

Numerous studies have been made of the relationship between streamflow and chemical load in the stream. The dilution theory principle (an average relationship between dissolved chemical load and stream discharge) is now widely accepted. A number of models have been proposed to describe the dilution theory (Carson and Kirkby 1962, Hendrickson and Krueger 1964, Toler 1965, Hem 1970, Hall 1971, Betson and McMaster 1975). However, this theory assumes both a relatively constant source of dissolved nutrients and a constant rate of release by weathering, independent of the volume of water passing through the soil. These models, therefore, are not suitable for evaluating nutrient outflux due to silvicultural activity because release is variable, depending upon vegetation uptake and microbiological processes.

The Loehr Study

In lieu of an adequate model, an evaluation of the relative impacts of non-point source nutrient pollution from silvicultural activities and other land uses has been published by Loehr (1974) and is presented here. Loehr compared available information on characteristics and relative magnitudes of certain non-point sources entering surface waters and commented on the feasibility of controlling these sources. Concentrations of organic and inorganic compounds representative of the range that could be anticipated from various non-point sources were compared. Loehr's results are displayed in figure X.1 and indicate that concentrations of nitrogen and phosphorus lost from forest lands approximate those found in precipitation. Additional data to support Loehr's findings are presented in figure X.2, and appendix X.B. Loehr's findings have been confirmed by all the data with the exception of the data from the Hubbard Brook experiment.

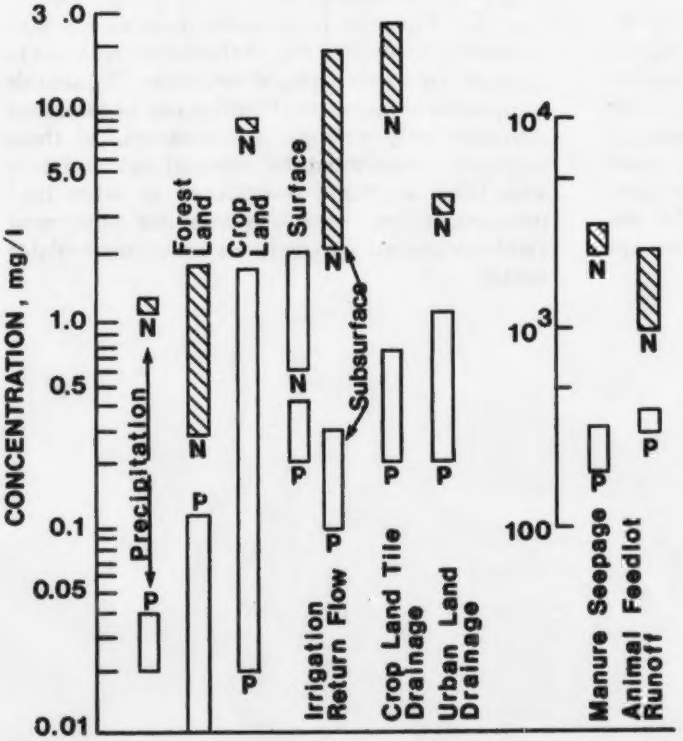

Figure X.1.—Range of total N and P concentrations found in various non-point sources (after Loehr 1974).

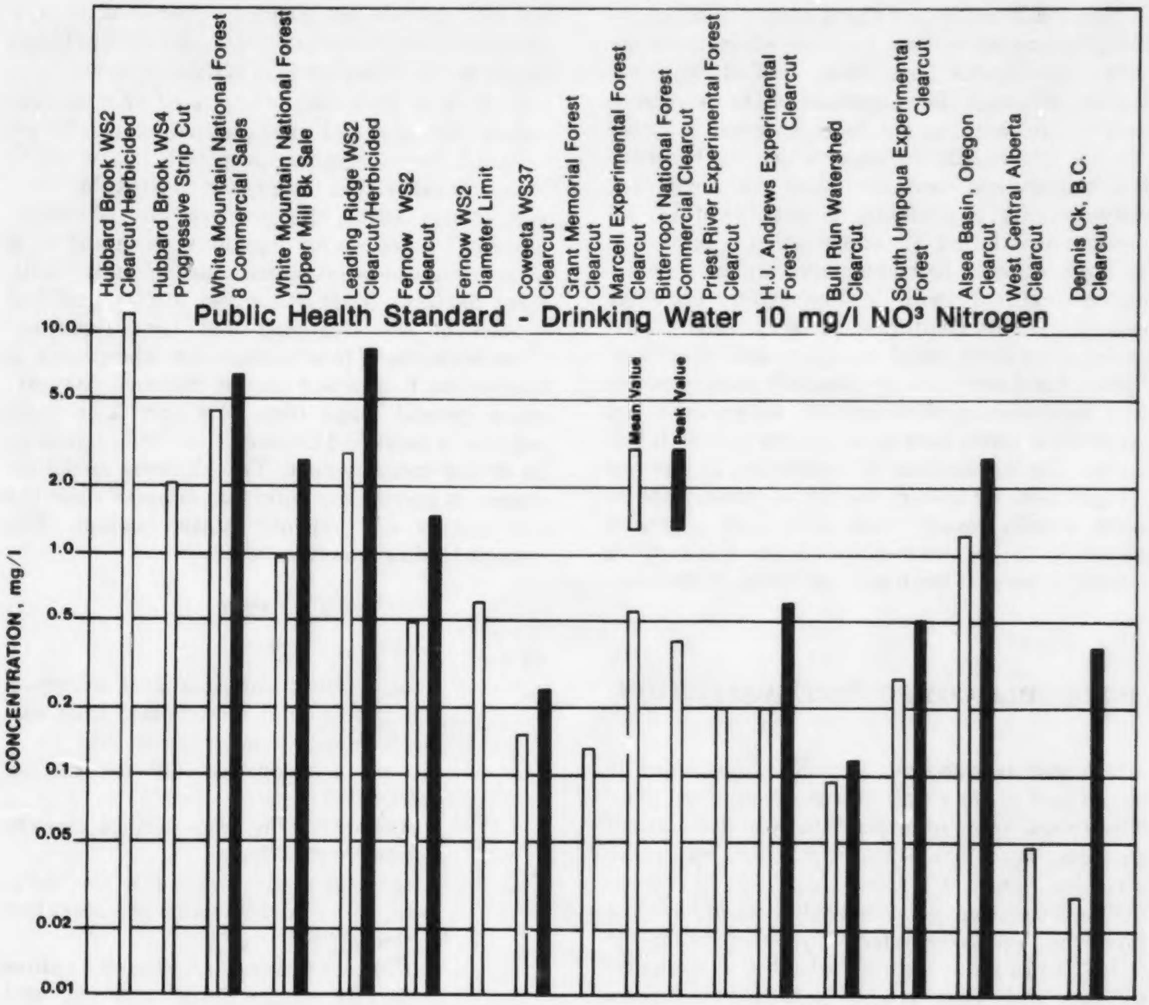

Figure X.2.—Summary of studies undertaken to quantify nitrogen release following silvicultural activities (see appendix X.B. for a more complete discussion of individual studies).

The Hubbard Brook Study

The potential problem of nutrient pollution in streams due to timber harvesting was made apparent in the late 1960's by a research study conducted at the Hubbard Brook Experimental Watershed in New Hampshire. The study was designed to quantify maximum water yield on a small watershed. This was done by cutting, limbing the fallen trees, and scattering the debris. However, none of the material was removed from the site. Herbicides were applied for 3 years following the cut to prevent reestablishment of vegetation. The nutrient outflow from the experimental area was measured. Following the treatment, concentrations of nutrients in the stream were significantly increased. Concentrations of NO_3^-–N (nitrate-nitrogen) were recorded which exceeded recommended public health drinking water standards of 10 mg/l by almost a factor of 2 (Likens and others 1970).

This study represents the application of an extreme treatment and not a normal silvicultural activity. Its results have been verified by other studies, although the magnitude of the changes in nutrient release has not been as great in other studies. The conditions under which the Hubbard Brook study was conducted show that significant water quality degradation is possible if (1) all vegetation is killed, (2) revegetation is prevented by application of herbicides, and (3) the soils are coarse textured, with a low cation exchange capacity. These conditions do not normally exist under prevalent land management practices. Silvicultural activities are presently constrained so that devegetation of a complete watershed is not generally a viable land management option. In addition, the application of herbicides to prevent revegetation is contrary to normal forestry operations. Finally, many forest soils have a greater capacity to fix nitrogen and phosphorus, or otherwise prevent the loss of nutrients from a site.

INSOLUBLE COMPONENT EVALUATION

Nitrogen in the soil is primarily organically bound and is not readily transported in solution. Nitrate and ammonium ions are available and can be transported in solution in the soil water and eventually reach a watercourse. The nitrate ion (NO_3^-) is the principal dissolved nitrogen form lost from the forest ecosystem; the ammonium ion (NH_4^+) is ordinarily strongly adsorbed to exchange surfaces and is not readily lost. However, these available forms of nitrogen — NO_3^- and NH_4^+ — make up only a small proportion of the total nitrogen present in soil.

Phosphorus in soil may be present in the organic or inorganic form. The soluble inorganic forms derived from chemical weathering or decomposition of organic matter are readily immobilized in the soil and are not easily leached from it. The primary mode of transport for organic forms of both nitrogen and phosphorus is surface erosion.

Outflux of insoluble, precipitated or adsorbed, organic nitrogen and total phosphorus can be estimated in a manner proposed by Midwest Research Institute in their report to EPA (McElroy and others 1976). As proposed by Midwest, "loading" functions for organic nitrogen and total phosphorus can be estimated based upon the "sediment loading" function derived from a modified version of the Universal Soil Loss Equation. Concentrations of total nitrogen and phosphorus in the surface foot of soil can be obtained from existing general maps (figs. X.3 and X.4), from regional or local Soil Conservation Service data, or by actual measurement. The Midwest model includes an enrichment ratio that is based upon the soil texture and organic matter content. The general loading function is:

$$Y = aSCr$$

where:

Y = total loading (organic and adsorbed nitrogen or total phosphorus) from surface erosion, lbs/ac/yr (kg/ha/yr),

a = dimensional constant (20 for English units or 10 metric units),

S = sediment loading from surface erosion, tons/ac/yr (MT/ha/yr),

C = total (organic nitrogen or total phosphorus) concentration in surface foot of soil, g/100g,

r = enrichment ratio, nitrogen values generally range from 2 to 5, and phosphorus values range from 1 to 3, with an average value of 1.5. The enrichment ratio is the concentration of nitrogen or phosphorus in the eroded material divided by its concentration in the soil proper (Massey and others 1953, Stoltenberg and White 1953).

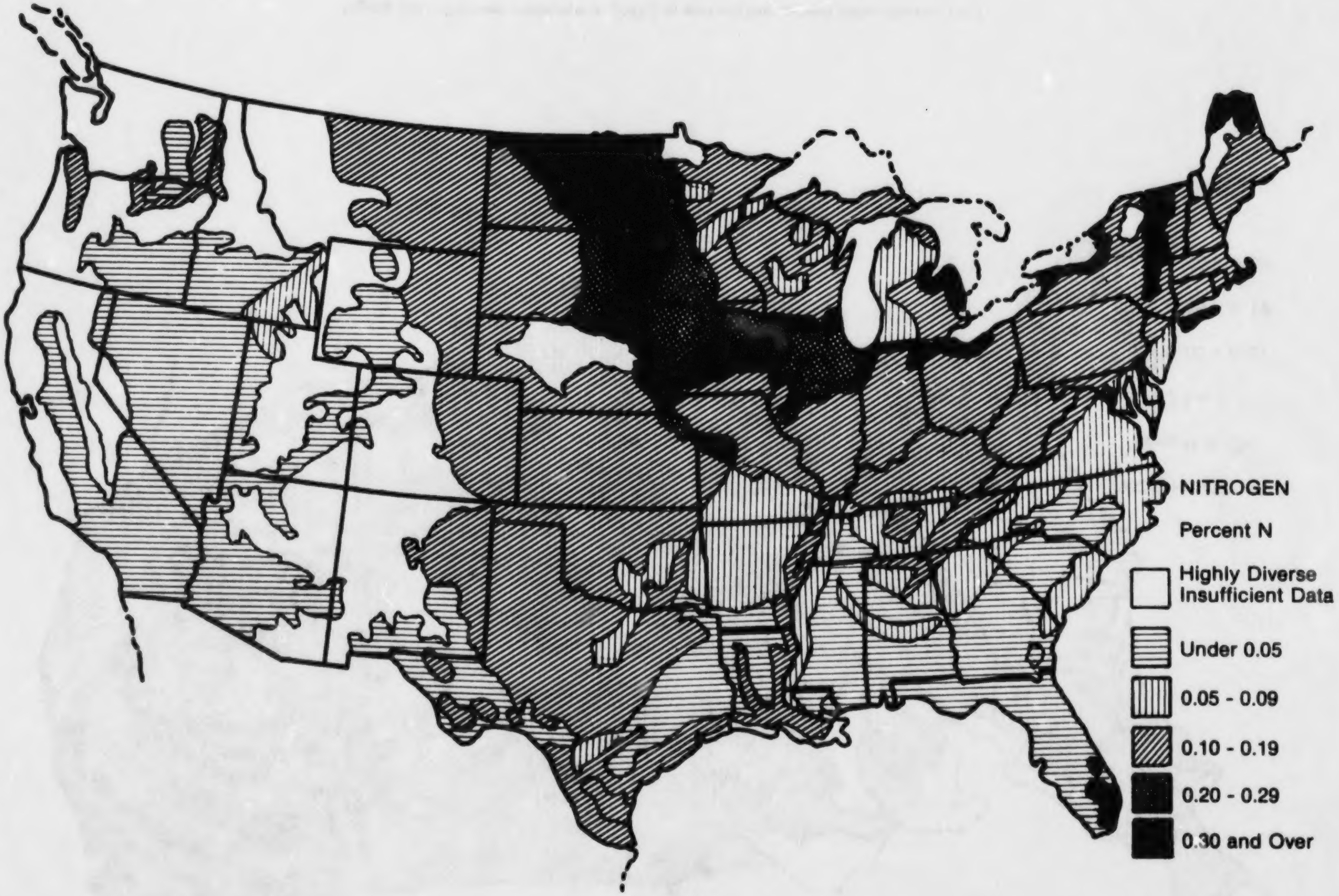

Figure X.3.—Percent nitrogen (N) in surface foot of soil (after Parker 1946).

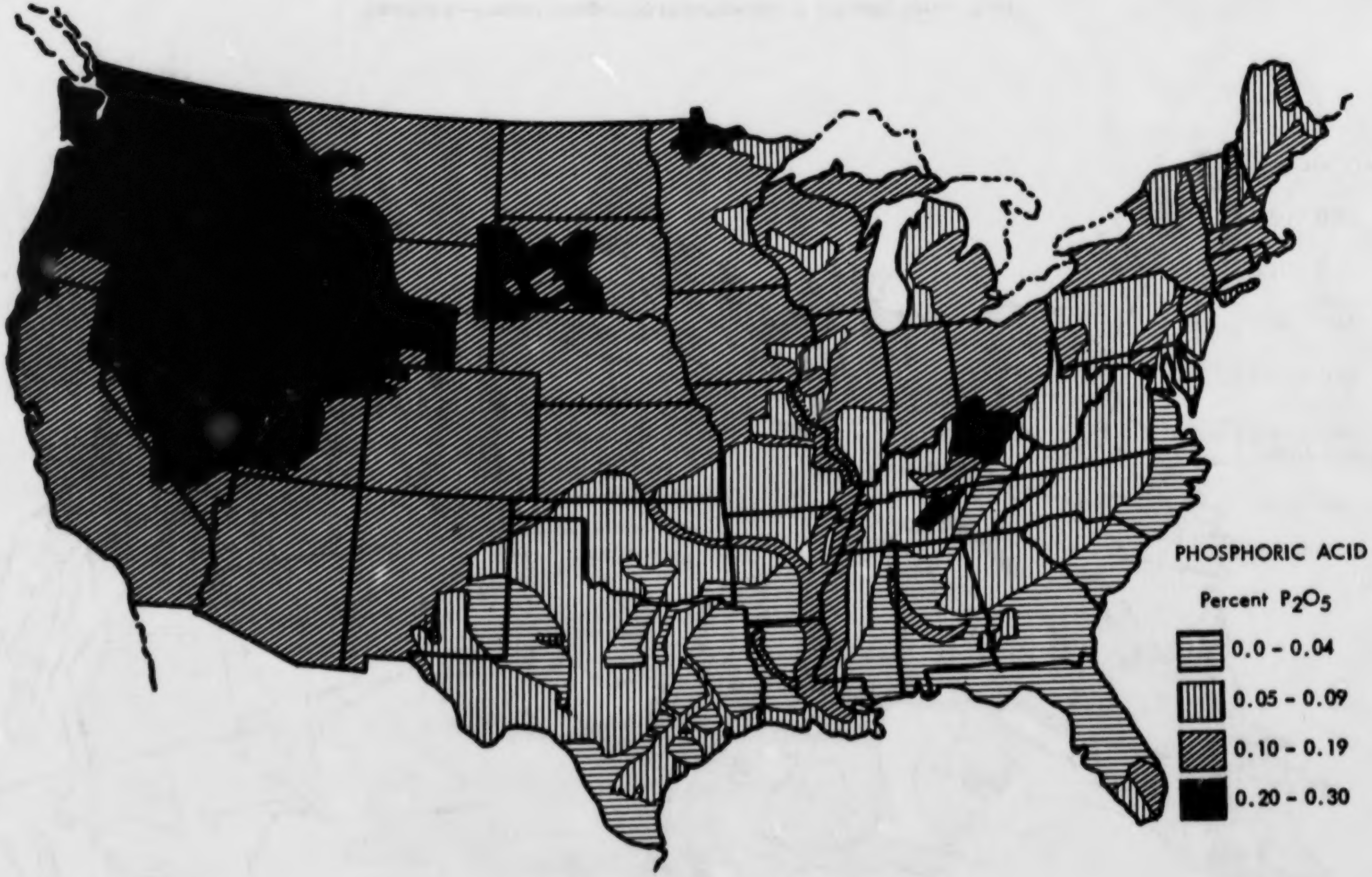

Figure X.4.—Percent phosphorus (P_2O_5) in surface foot of soil (after Parker 1946).

APPLICATIONS, LIMITATIONS, AND PRECAUTIONS

The insoluble component model represents the current state-of-the-art; however, it has not been adequately tested in forested situations and should be used with caution.

CONCLUSIONS

Reinhart (1973), Loehr (1974), Patric and Smith (1975), and Sopper (1975) evaluated available studies and concluded that normal silvicultural operations do not raise nitrogen and phosphorus concentrations above public health standards for drinking water. Loehr (1974) concluded:

> Control of forest land runoff and range land runoff does not appear to be necessary at this time because the concentrations and yields of constituents are comparable to those of precipitation. These two non-point sources, forest runoff and range land runoff, may generally be considered as background sources unless current practices or available data change drastically.

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APPENDIX X.A:
DETAILED DISCUSSION OF THE NUTRIENT CYCLE

The forest nutrient cycle is generally segmented into three compartments — input, intracycle, and output. The action and interaction of the major compartments of the process are depicted in figure X.A.1. Placing the nutrient cycle in such a format forces the investigator to consider the processes and variables that are likely to be impacted by silvicultural activities and the effect that these changes will have on soil and water chemistry.

INPUT TO THE NUTRIENT CYCLE

Nutrient inputs to a forest ecosystem come principally from (1) the atmosphere, (2) the soil and underlying bedrock, and (3) depositions by floods on alluvial terraces. Alluvial deposition is not a dominant nutrient input factor for many of the forested areas. Man enters the cycle with fertilizer additions.

Atmosphere

Atmospheric inputs account for most of the nutrients entering the cycle, usually during a precipitation event, in the form of dissolved gases, aerosols, and solid particulate matter. Nonprecipitation events, commonly referred to as dry fall, also contribute solid particulate matter; and in some areas, aerosols are carried by prevailing winds and storm tracts from cities, industrial centers, and agricultural lands, then deposited on the forest without benefit of a precipitation event (U.S. Senate Hearings 1971, Jorgensen and others 1975). Deposition of dry fall and aerosols may occasionally be extensive during initiation of a precipitation event, when these materials are "washed" from the atmosphere. In any event, precipitation falling on a forested area is not chemically pure water but may contain many chemical compounds, ranging from beneficial nutrients (such as nitrogen) to deleterious acid compounds (U.S. Senate Hearings 1971). An extensive coverage of the addition of acidic materials to the forest ecosystem can be found in the "Proceedings of the First International Symposium on Acid Precipitation and the Forest Ecosystem" (Dochinger and Seliga 1976).

Atmospheric Nitrogen

Precipitation contains significant quantities of numerous substances including nitrogen; one of the primary sources of nitrogen input to the forest ecosystem is through the atmosphere (fig. X.A.1). Nitrogen occurs in the gaseous form — principally as N_2, NO, NO_2 and NH_3, and in aerosols — as NH_4^+ and NO_3^-. However, the gaseous nitrogen form N_2 is considered inert and cannot be directly utilized by most organisms. Biological fixation by microorganisms during the intracycle process (discussed in detail in "The Intracycle Process") converts free nitrogen to the ammonia form which is then utilized in biological functions.

The compounds named are naturally produced; however, increasingly large concentrations of them are the result of industrial activities, vehicle exhausts, and agricultural operations (Feth 1966, Robinson and Robbins 1970). Transport of relatively large quantities of nitrogenous compounds from various concentrated pollutant sources by prevailing winds or storms has resulted in the deposition of large amounts of these materials (Likens and others 1976). Such deposition occurs not only as dissolved and particulate matter in precipitation, but it also occurs during nonprecipitation periods as dry fall and aerosol deposition. Junge (1958) reported a nationwide survey of ammonium and nitrate in rainwater over the United States. The study indicated that concentrations of NH_4^+ and NO_3^- varied markedly. Nitrogen input values have been estimated for the United States and are presented in figure X.A.2. It should be noted that the values are based on regional averages and specific sites can differ markedly from the regional values due to local conditions.

Electrochemical and photochemical fixation, lightning, and radiation convert a limited amount of elemental nitrogen to available inorganic forms.

Atmospheric Phosphorus

Precipitation may also be a source of phosphorus input into the system, but the quantities involved can generally be assumed to be minor in comparison to those from the weathering of soil and rock (Tabatabai and Laflen 1976).

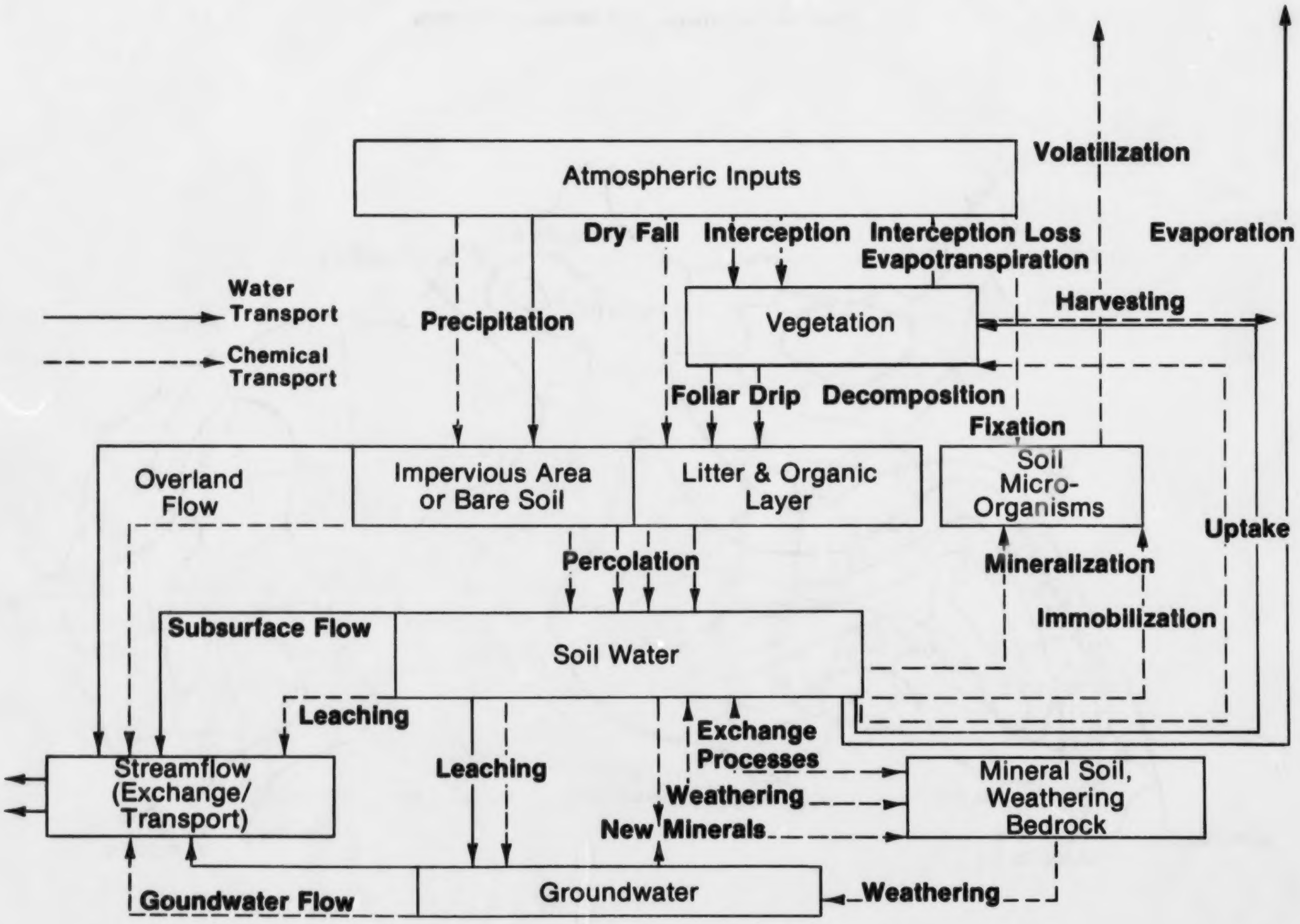

Figure X.A.1—Biochemical cycle for nitrogen in a forest.

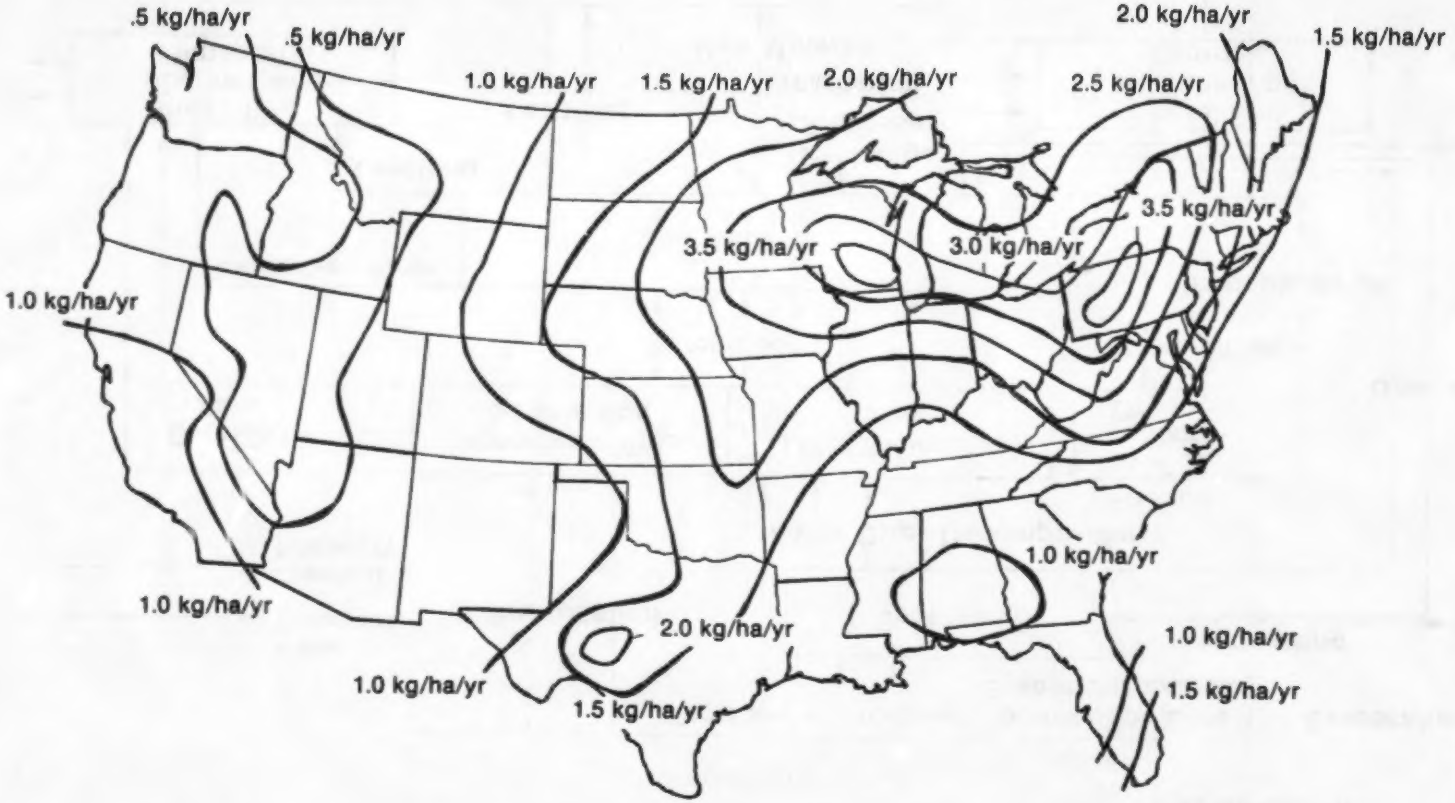

Figure X.A.2.—Nitrogen (NH_4^+ and NO_3^-) in precipitation.

Soil and Rock

Chemical decomposition and physical weathering of the soil and bedrock continually release nutrients to the ecosystem. Soil and bedrock are the principal sources of metallic cations, phosphorus, and trace metals.

Soil. — Weathering and decomposition of the solum and regolith add significant amounts of nutrients to the forest and the intracycle processes. Weathering and decomposition occur much more rapidly within the upper soil horizons (i.e., rooting zone) where plants, animals, bacteria, and soil fungi all contribute to decomposition of the soil and secondary minerals, and where the physical processes, particularly freezing and thawing, accelerate the weathering of the soil and rock (Lutz and Chandler 1961).

Bedrock. — Geologic weathering and decomposition of bedrock are not primary sources of nutrient input to the forest ecosystem over a short period (i.e., timber rotation age), in that nutrients released from rock do not normally enter the forest ecosystem directly through the intracycle processes, but are removed from the system via deep ground water. An exception occurs when the root zone penetrates to bedrock.

Nitrogen Inputs From Soil and Rock

Geologic formations do not have large amounts of nitrogen present, so nitrogen inputs to the forest ecosystem from geologic weathering and chemical decomposition are insignificant, especially when compared with nitrogen inputs from the atmosphere.

Phosphorus Inputs From Soil and Rock

Phosphorus input to the forest ecosystem comes almost exclusively from chemical decomposition of rocks. Phosphorus is estimated to rank eleventh among elements in igneous rocks. It occurs in all known minerals as phosphates (McCarty 1970). Apatites, the principal minerals containing phosphorus, are found in almost all igneous and sedimentary rocks. Phosphorus in soil can be classed generally as organic or inorganic. Phosphorus is found predominantly in the mineral fraction in combination with a heavy metal, iron, aluminum, or magnesium (McElroy and others 1976).

Forest Fertilization

Introduction of nitrogen and phosphorus to the forests by fertilization can be a potentially significant input source. However, at the present time forest fertilization has not been extensively undertaken and has been limited to the Pacific Northwest and to the Southeast. Fertilization is the only major nitrogen input source that the forest land manager can control. A more complete evaluation of its use and potential water quality degradation is presented in "Chapter XI: Introduced Chemicals."

The introduction of phosphorus to the forest by fertilization may also be a significant input in some locations but, as mentioned previously, forest fertilization is not being applied to large acreages nationally. See "Chapter XI: Introduced Chemicals," for a more complex discussion.

THE INTRACYCLE PROCESS

Intracycle processes (fig. X.A.1) are numerous and varied. Nutrients entering the ecosystem in available form are utilized by vegetation and animals and become unavailable (i.e., they become stored nutrients). The transfer rate of nutrients between living organisms (vegetation and animal), forest floor, and mineral soil is dependent upon the nutrient's chemical and physical characteristics and physiological function (Jorgensen and others 1975).

Intracycle Nitrogen

Mineralization

Mineralization, or ammonification, is accomplished by heterotrophic bacteria, actinomycetes, and fungi. These ammonifying microorganisms[1] metabolize organic nitrogen —

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[1] *Two general groups of organisms fix nitrogen — symbiotic nitrogen fixers and free-living nitrogen fixers. Symbiotic organisms are associated with legumes, and several tree species, notably alder. The quantity of nitrogen fixed by symbiotic organisms exceeds that fixed by free-living nitrogen fixers by a factor of 100. Symbiotic nitrogen fixers are restricted to the terrestrial environment, whereas free-living nitrogen fixers are found in both terrestrial and aquatic environments. Azotobacter, Clostridium, and blue-green algae are the primary free-living nitrogen fixers (Stewart 1975, Weber and Gainey 1962, Kormondy 1976).*

amino acids, urea, uric acids and peptone (usually in the form of an amine group, $^-NH_2$) — to an inorganic form, ammonium. Excess ammonium produced by the organisms is released; some of this nitrogen is lost from the soil to the atmosphere as gaseous ammonia, NH_3 (Kormondy 1976).

Mineralization is the principal nitrogen process conducted by microorganisms in highly acidic soils. DeByle and Packer (1972) reported that nitrification rates were barely detectable in acid soils under a coniferous stand. They concluded that ammonium was probably the principal form of available nitrogen present and that because of its high solubility could easily be lost in deep seepage or overland flow.

However, most of the nitrogen remains within the forest ecosystem, being utilized by soil microorganisms or vegetation, becoming adsorbed on clay and organic colloids (through cation exchange), and by remaining in solution in the soil water (Bormann and Likens 1967).

Nitrification

Nitrification (fig. X.A.3) is the biological conversion of organic or inorganic nitrogen compounds from a reduced to a more oxidized state, NO_3^-. Although nitrification usually applies to autotrophic oxidation of ammonia or nitrate ions, numerous heterotrophs, including bacteria, algae, and fungi are known to oxidize organic nitrogen to nitrite or nitrate. It is generally acknowledged that the rate of nitrogen oxidation by heterotrophs is negligible compared to that by autotrophs. Autotrophic nitrifying bacteria are confined largely to Nitrosomonas (oxidation of NH_4^+ to NO_2^-) and Nitrobacter (oxidation of NO_2^- to NO_3^-); however, five other genera have also been shown to oxidize nitrogenous compounds. Adequate oxygen must be present for nitrification to occur. Nitrification has been detected in aquatic systems with approximately 0.3 ppm dissolved oxygen (Greenwood 1962).

For most soils, nitrification depends very much on pH. It usually decreases greatly at a pH below 6.0 and becomes negligible at a pH of 5.0 (Alexander 1967). The Hubbard Brook study, where nitrification rates were increased in an acid soil (pH 4) following a complete clearcut, is a particularly notable exception to the norm. It was hypothesized by the investigators that the increased nitrification rate was caused by a little known species of nitrifying bacteria adapted to more acid conditions (Likens and others 1970). Nitrate and nitrite, end products of the nitrification process, are the principal components of nitrogen outflux from the forest ecosystem. (This process is discussed in more detail under "Outputs From the Nutrient Cycle — Nitrogen Outflux" in this appendix.)

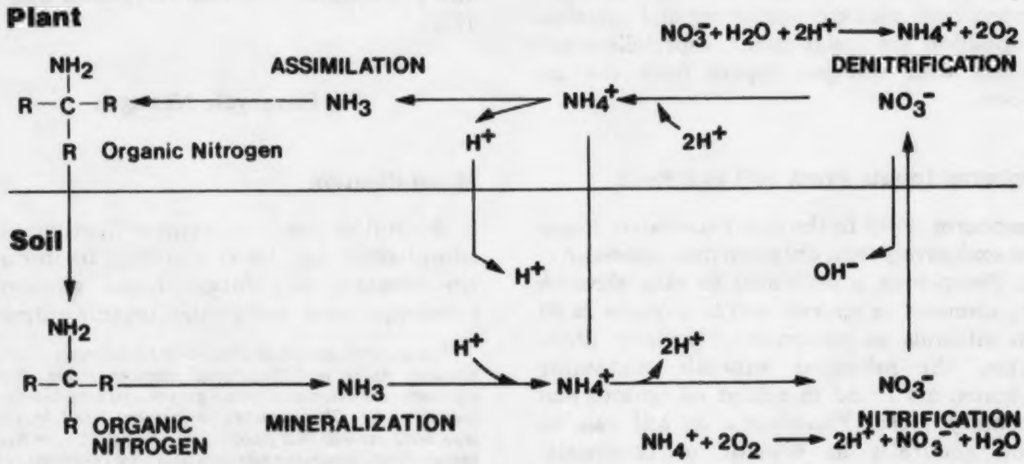

Figure X.A.3.—Simplified nitrogen cycle showing N utilized in the nitrate (NO_3^-) and ammonium (NH_4^+) forms and showing acid and base relations associated with the various processes (after Reuss 1976).

The intracycle nitrogen processes have been intensively investigated at the Coweeta Experimental Forest, North Carolina. A relatively undisturbed oak-hickory stand was selected, and a flow model of the nitrogen cycle for this forest was prepared. An estimate of the nitrogen pools, vegetation increments of nitrogen, and transfer rates among the various compartments was made and is illustrated in figure X.A.4. The model shows that most of the nitrogen in the undisturbed forest is contained in large storage pools that turn over slowly. Over 80 percent of the total nitrogen in this forest ecosystem is bound within soil organic matter, with about 11 percent in total vegetation, 3 percent in litter, 4 percent in microbial biomass, and 2 percent in free soil (Mitchell and others 1975, and Waide and Swank 1976).

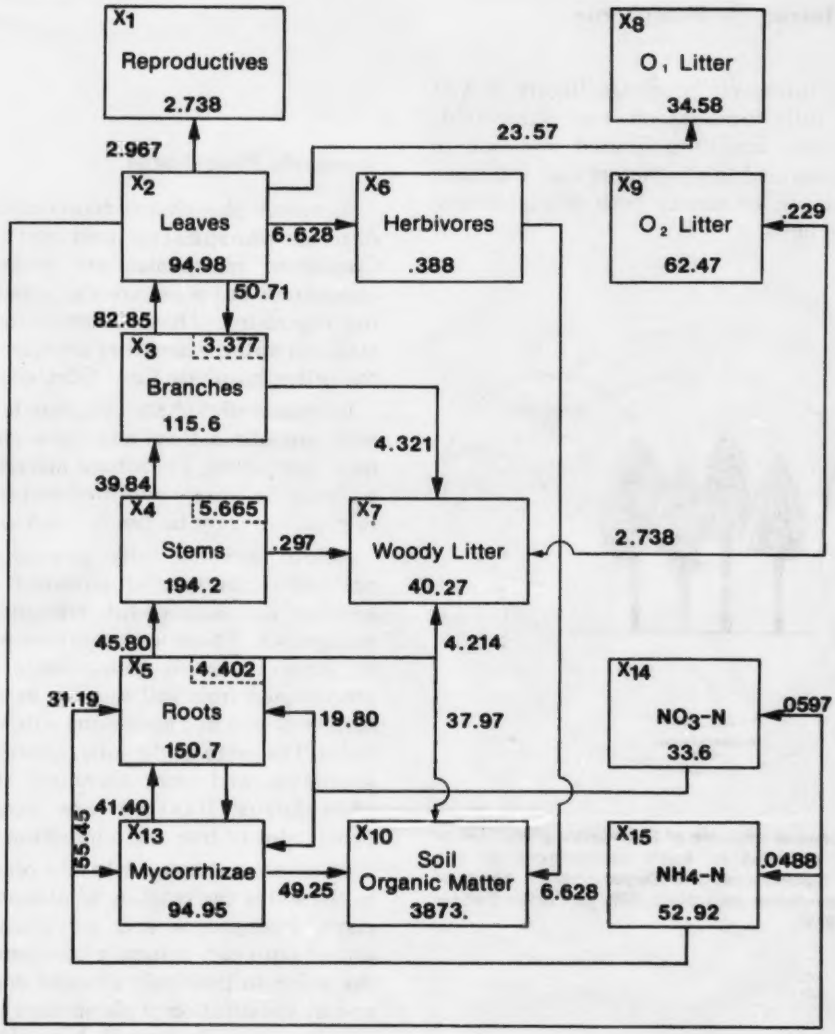

Figure X.A.4—Flow model of nitrogen cycling in an oak-hickory forest at Coweeta Experimental Forest, North Carolina. Values inside boxes represent standing crops of nitrogen (kg N/ha); values inside dotted lines are vegetation increments (kg N/ha/yr); numbers on arrows represent nitrogen transfers among compartments (kg N/ha/yr). This diagram shows nitrogen transfer associated with nitrogen uptake by plants and return to litter-soil pools (after Waide and Swank 1976).

Although the values presented in the flow model are valid only for the specific site studied, the flow model itself has general applicability to all forest types. Detailed analyses, similar to the one undertaken in this study, are necessary to quantify the actual amounts and rates of nitrogen in the cycle, but are not feasible except in a research environment. Forest managers could utilize the results of such studies to evaluate the potential impacts of changing the nitrogen cycle.

Intracycle Phosphorus

Phosphorus intracycle processes (figure X.A.5) are neither fully understood nor quantified. Research to date has been limited in scope to general processes and to site factors that influence them. Phosphorus occurs as both inorganic and organic compounds.

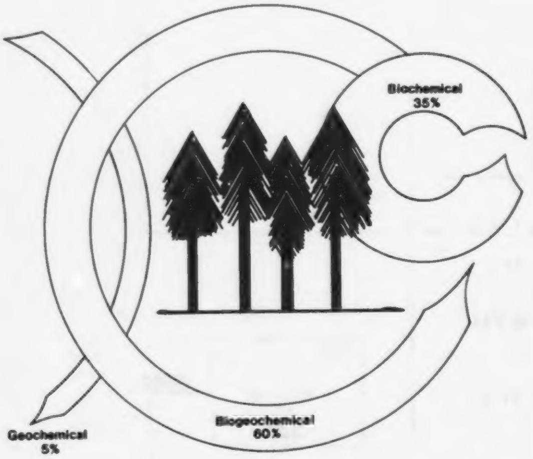

Figure X.A.5—General estimate of the relative proportion of phosphorus present in each component of the geochemical, biochemical, and biogeochemical cycles of loblolly pine plantation ecosystem, 20th year (after Switzer and Nelson 1972).

Organic Phosphorus

Organic phosphorus compounds found in forest soils and water are products of biochemical reactions. Almost no information is available to identify specific compounds or groups of compounds that may make up the dissolved organic phosphorus fraction of waters draining a forested ecosystem (Stumm and Morgan 1970). It has been estimated that about 40 to 50 percent of the organic soil phosphorus consists of nucleic acids, inositol phosphate and phospholipids; the remainder is largely unidentified. It is known that decomposition of organic matter results in the mineralization of organic phosphorus and the release of inorganic phosphate. Actual chemical reactions involved are not fully known.

Inorganic Phosphorus

Inorganic phosphorus compounds occur as condensed phosphates and orthophosphates. Condensed phosphates are generally manmade compounds but some are also generated by all living organisms. These latter compounds are unstable in water, where they are slowly hydrolyzed to the orthophosphate form (McCarty 1970).

Inorganic phosphate compounds generally react with metallic cations and clays present in soil to form complexes. Phosphate materials held by the soil may be loosely adsorbed and remain available to plants or may be firmly fixed and unavailable.

Acidic mineral soils generally contain appreciable quantities of adsorbed aluminum and smaller but significant amounts of iron and manganese. These ions combine with phosphates to form insoluble compounds that may be precipitated from soil solution or adsorbed on the surface of iron and aluminum oxides or on clay particles. The more acidic soils contain more adsorbed aluminum and iron; therefore, the products of phosphorus fixation are largely complex phosphates of iron and aluminum.

Another mechanism whereby phosphorus is fixed in the soil is the reaction of phosphates with silica clays. Phosphorus and polyphosphates are adsorbed onto clay minerals by chemical bonding of the anion to positively charged edges of the clays and by substitution of phosphates for silicate in the clay structure. In general, high phosphate adsorption by clays occurs at lower pH values (Stumm and Morgan 1970); in most soils phosphorus availability is at a maximum in the pH range 5.5 to 7.0 and decreases as the pH drops below 5.5 (Tisdale and Nelson 1966).

OUTPUTS FROM THE NUTRIENT CYCLE

Nutrients are naturally lost from the forest ecosystem in the form of dissolved or particulate matter in moving water or colluvium or both, through removal of the vegetation, through the diffusion or transport of gases or particulate matter by wind, and by fire or by animal activity. Gaseous exchange from the soil and vegetation to the atmosphere has not been extensively studied, but it does not appear that this would account for appreciable nutrient loss.

Dissolved Materials

Nutrients are lost from the system in overland flow, subsurface flow and ground water. Numerous studies have shown that overland flow rarely occurs within an undisturbed forest (Colman 1953); and even following silvicultural activities, overland flow does not normally contribute significantly to watershed discharge.

The chemical content of subsurface flow and ground water depends on both biochemical and geochemical cycles. Thus the chemical composition will vary regionally and seasonally depending on variations in rates of decomposition of organic matter and immobilization by microorganisms, differences in weathering and exchange processes, and changes in concentration brought about by vegetative uptake. Nutrients carried in the water draining a forest ultimately enter the streams and determine the chemical character of the receiving stream.

Removal Of Vegetation

Timber harvesting results in the loss of nutrients from the forest ecosystem. The proportion of nutrients in the vegetation lost from the forest is determined by the utilization that is made of the tree, being maximized when the entire tree (bole, limbs, foliage, and roots) is utilized and minimized when only the bole is removed from the site. The removal of overstory vegetation results in accelerated decomposition of organic matter on and in the forest floor due to an increase in soil temperature and moisture content. Increased soil temperatures are caused by removal of the shading trees, which allows direct solar heating of the soil surface. Soil water loss (i.e., evapotranspiration) is reduced, which increases soil moisture. Nutrients made available in the soluble form during the decomposition processes may exceed nutrient uptake capacity of the vegetation remaining on the site. Excess available nutrients then become lost from the forest ecosystem in surface and ground water flows to streams and deep seepage (Cramer 1974).

Nitrogen Outflux

Pathways Of Nitrogen Removal

Nitrogen is lost from a forest ecosystem by volatilization, removal of the biomass through harvesting, and by leaching to surface and subsurface flows.

Volatilization. — Generally, volatilization losses are extremely limited due to the nature of the forest environment. However, large volatilization losses of nitrogen occur when forest and logging residue are burned. Wildfire and prescribed burning of slash result in loss of organic nitrogen in the vegetation (DeBell and Ralston 1970). Grier (1975) reported that a wildfire on the Entiat Experimental Forest, Washington, caused a reduction of 97 percent of the nitrogen in the forest floor and two-thirds of the nitrogen in the A_1 horizon of the mineral soil. Ash from fires may be carried by the wind or by surface erosion into a watercourse. Losses via volatilization were discussed in "Nitrification and Mineralization."

Removal of the biomass. — Nitrogen assimilated by vegetation and utilized in biomass production is lost from the site when the vegetation is harvested and physically removed from the site.

Surface and subsurface flow. — Nitrogen loss from a site in the surface water or soil water has direct and immediate impact on the quality of water draining a forested area. Nitrogen may be in solution (principally as NO_3^-) or transported by the water adsorbed to suspend particles (principally as NH_4^+ and organic compounds). The intracycle processes — mineralization and nitrification — that have as their end products nitrate and ammonium, will be discussed in the next section. Nitrogen losses associated with surface erosion (i.e., adsorbed nitrogen) may be estimated using the insoluble component model previously presented.

Nitrification And Mineralization

The acid-base relations associated with nitrification and mineralization are shown in figure X.A.3. Acidity of the system remains unchanged as long as plant uptake of nitrogen equals the rate of mineralization of nitrogen and neither NH_4^+ nor NO_3^- accumulates in the soil.

When mineralization occurs followed by nitrification, an excess of hydrogen ions (H^+) is released, which may replace cations on the exchange sites. If plant uptake of nitrate does not take place, both nitrate ions and metallic cations are subject to leaching by subsurface flow. Bormann and Likens (1970) found that excess hydrogen ions may be released from exchange sites and go into solution in soil water, and are thereby lost from the forest ecosystem. The result is an increased outflux potential of nutrients from deforested watersheds that have increased nitrification rates. They reported that increased concentrations of calcium, magnesium, sodium, and potassium in water draining a clearcut occurred almost simultaneously with increased nitrate concentration.

Nitrate, an end product of nitrification reactions of the intercycle stage, is the principal component of nitrogen outflux from the forest ecosystem. Increased biological nitrification may result from silvicultural activities that reduce the vegetative cover, thus resulting in increased soil temperatures and moisture.

Accelerated nitrogen losses following some silvicultural activities have generally been attributed to changes in the forest floor environment conducive to nitrifying bacteria and to a reduction in assimilation due to the reduced vegetative cover.

Microbial populations in the forest floor generally increase following a timber harvest that exposes the soil to increased radiation, which results in warmer soil temperatures. Little decomposition takes place during the period when the soil is frozen or covered with snow. Thus, temperature of the growing season appears to be the decisive factor (Johnsen 1953, and Mikola 1960). The potential increase in nitrification rates is greater in the northern climates, where thick humus layers accumulate on the mineral soils and temperatures of shaded soils remain low most of the year (Stone 1973).

Soil moisture also influences the growth of microbial populations: removal of the overstory vegetation reduces interception and transpiration losses which results in increased soil moisture. Saturated soils, however, may retard microbial growth and thus reduce nitrification rates.

If nitrification and plant uptake of ammonium ions are less than the rate of mineralization, ammonium accumulates in the soil (fig. X.A.3). Ammonium ions are adsorbed on cation exchange sites and are not readily leached. Clay soils and soils with high cation exchange capacities hold ammonium ions most efficiently. Leaching of NH_4^+ occurs in soils with higher pH and lower cation exchange capacity (Coffee and Bartholomew 1964).

Denitrification. — Denitrification, the biochemical reduction of nitrate and/or nitrite, is one possible route whereby nitrogen may be lost from the forest ecosystem — microorganisms may reduce the nitrate and/or nitrite forms of nitrogen to gaseous nitrogen, and in some cases these forms are reduced to ammonia. Denitrification will occur in any microbial microenvironment that is essentially anaerobic. The microorganisms utilize the nitrogen oxides as a source of oxygen in the presence of glucose and phosphate. The rate of denitrification is partially controlled by pH. Denitrifying microorganisms are active in soils that range in pH from 5.8 to 9.2 (with an optimal value between pH 7.0 and 8.2).

Many commercial forest lands have soil pH values below 5.8 and are normally aerobic; therefore denitrification is severely limited, if detectable at all (Lutz and Chandler 1961, and Keeney 1973).

Phosphorus Outflux

Phosphorus is lost from the forest ecosystem in surface and subsurface water, and in vegetation removed from the site during silvicultural activities. Water quality is affected only by phosphorus lost from the site and entering the stream. Phosphorus loss via water transport includes not only the phosphorus dissolved in water, but also that adsorbed to suspended solids.

Generally, the greatest loss of phosphorus from a forest will occur as insoluble phosphorus complexes adsorbed on the clay-sized materials that are transported by surface flow. Research investigations (app. X.B.) have generally not reported significant increases in phosphorus concentrations in the receiving streams following silvicultural activities. It would appear that increases in available phosphorus due to silvicultural activities are normally utilized or fixed, and only a small fraction is transported from the site to a watercourse in the absence of excessive erosion.

APPENDIX X.B:

EIGHTEEN STUDIES OF NUTRIENT RELEASES FOLLOWING SILVICULTURAL ACTIVITIES

The results of research investigations into nutrient release of nitrogen and phosphorus following silvicultural activities are summarized and presented in figure X.2. A more thorough presentation of the results of these investigations is presented in the following 18 studies.

The Hubbard Brook study initiated concern regarding nutrient release following clearcutting and is presented first (study X.B.1.). It should be noted that the treatment was extreme. The NO_3^-–N and NH_4^+–N concentrations were greater in the precipitation than in the streams draining the control watersheds.

Concentrations of nitrogen and phosphorus in the control watersheds may be used as estimates of baseline water quality for the various geographic areas studied. It should be realized, however, that there may be considerable variation between adjacent watersheds as well as between geographic areas.

Study X.B.1
Hubbard Brook Experimental Forest, New Hampshire

Silvicultural treatment: Watershed 2 had all trees and brush cut (but left in place) during November and December 1965, and herbicides were applied during the following three summers to inhibit regrowth. Watersheds 4 and 6 were undisturbed and were used as controls.

Vegetation: Northern hardwoods — beech, birch, and maple.

Drainage: Treated, Watershed 2, 39 ac (15.6 ha).
Control, Watershed 4, 90 ac (36 ha).
Control, Watershed 6, 33 ac (13.2 ha).

Sampling: October 1965-September 1968.

Results:

Study and year	NO_3-N Mean annual	NH_4^+-N Mean annual	Total dissolved P Maximum	Total dissolved P Mean annual
	mg/l			
Watershed 2				
1965-66	0.21	0.11	---	---
1966-67	8.67	0.05	---	---
1967-68	11.94	0.04	0.0026	0.00156
Watershed 4				
1965-66	0.19	0.09	---	---
1966-67	0.20	0.05	---	---
Watershed 6				
1965-66	0.19	0.09	---	---
1966-67	0.16	0.04	---	---
1967-68	0.29	0.02	---	0.00118
Precipitation				
1965-66	0.32	0.16	---	---
1966-67	0.34	0.14	---	---
1967-68	0.35	0.17	---	---

Sources: Likens and others 1970; Hobbie and Likens 1973.

Study X.B.2
Hubbard Brook Experimental Forest, New Hampshire

Silvicultural treatment:	Progressive strip cutting. A 90 ac (36 ha) watershed was divided into 49 east-west strips, each 82 ft (25 m) wide. Every third strip was clearcut in October 1970. The remaining strips are cut at 2-year intervals.
Vegetation:	Uneven-aged northern hardwoods — beech, birch, and maple.
Drainage:	Treated, Watershed 4, 90 ac (36 ha).
Sampling:	January 1968-September 1972.

Results:

Date	NO_3^-–N Average concentration Estimated (If untreated)	Actual	Date	NO_3^-–N Average concentration Estimated (If untreated)	Actual
	-------- mg/l	--------		-------- mg/l	--------
November 1970	0.43	0.56	November 1971	0.11	1.54
December 1970	0.50	0.70	December 1971	0.13	1.76
January 1971	0.61	0.74	January 1972	0.38	1.72
February 1971	0.68	0.79	February 1972	0.36	1.44
March 1971	0.70	0.88	March 1972	0.61	2.08
April 1971	0.86	1.24	April 1972	0.72	1.90
May 1971	0.52	0.77	May 1972	0.61	1.72
June 1971	0.16	0.25	June 1972	0.09	0.72
July 1971	0.11	0.25	July 1972	0.07	0.56
August 1971	0.04	0.34	August 1972	0.11	0.63
September 1971	0.02	0.43	September 1972	0.02	0.47
October 1971	0.02	1.15			

[1] No noticeable change in NH_4^+ concentration between treated and control watersheds.

Source: Hornbeck and others 1973.

Study X.B.3

White Mountain National Forest,
New Hampshire

Silvicultural treatment:	Timber sales conducted on the White Mountain National Forest. All areas were clearcut; more than 75 percent of the timber was cut. Adjacent undisturbed watersheds were also monitored.
Church Pond:	Clearcut in summer 1969, 329 ac (133 ha); 10 ac (4 ha); watershed monitored.
Conner Brook:	Clearcut in May 1969-Dec. 1969, 282 ac (114 ha); three 20 ac (8 ha) watersheds were monitored.
Davis Brook:	Clearcut Sept. 1969-Sep 1970, 160 ac (65 ha); three watersheds were monitored — 2.5 ac (1 ha), 7 ac (3 ha), 10 ac (4 ha).
D.O.C. Creek:	Clearcut July 1970, 126 ac (55 ha); two 20 ac (8 ha) watersheds were monitored.
Gale River:	Clearcut Dec. 1968-Aug. 1970, 297 ac (120 ha); three watersheds were monitored — two 10 ac (4 ha) and one 5 ac (2 ha).
Greeley Brook:	Clearcut initially 1960 and again 1967, 371 ac (150 ha); three watersheds were monitored — 35 ac (14 ha), 10 ac (4 ha) and 5 ac (2 ha).
HB 101:	Clearcut Nov. 1970, 30 ac (12 ha); 25 ac (10 ha) watershed monitored.
Stony Brook:	Clearcut Nov. 1968-May 1970, 160 ac (65 ha); 10 ac (4 ha) watershed monitored.
Vegetation:	Northern hardwoods (beech, birch, and maple) were present on all areas except Greeley Brook which had predominantly red spruce.
Drainage:	See "Silvicultural treatment," above.
Sampling:	Biweekly analysis from April-November 1971.

Results:

Watershed	NO_3-N Max	NO_3-N Mean
	------ mg/l	-------
Church Pond		
Control	0.95	0.81
Clearcut	1.60	1.40
Conner Brook		
Control	0.40	0.20
Davis Brook		
Control	0.09	0.02
Clearcut	5.26	3.84
D.O.C. Creek		
Control	1.22	0.52
Clearcut	3.54	1.90
Gale River		
Control	0.50	0.20
Clearcut	6.39	4.47
Greeley Brook		
Control	0.79	0.54
Clearcut	1.85	1.31
Stony Brook		
Control	0.81	0.18
Clearcut	3.73	1.99

Source: Pierce and others 1972.

Study X.B.4

White Mountain National Forest,
Upper Mill Brook, New Hampshire

Silvicultural treatment: Harvesting operations were conducted on the Upper Mill Brook sale area from December 1971-February 1973

Watershed No.	Date	Treatment and drainage area
1	Jan.-Feb. 1972	Thinning (10-20 ac)
2	Feb.-Mar. 1972	Thinning (10-20 ac)
3	Dec. 1971-Jan. 1972	Clearcut (10-20 ac)
4	Dec. 1971-Jan. 1972	Clearcut (20-30 ac)
5	June-Sept. 1972	Clearcut with buffer (10-20 ac)
6	Sept. 1972-Feb. 1973	Clearcut (10-20 ac)
8	---	Control (30-40 ac)
9	---	Control (20-30 ac)
C	---	Control (620 ac)

Vegetation: Northern hardwoods.

Drainage: See "Silvicultural treatment," above.

Sampling: 1972-1974, 10 to 12 samples per year were collected. This number of samples was based on previous data evaluations.

Results

Watershed and treatment	NO_3-N Mean	NO_3-N Max	Total N Mean	Total N Max	PO_4^{3} Mean	PO_4^{3} Max
	mg/l					
1 and 2—thinnings	0.45	2.10	0.92	2.50	0.02	0.11
3—clearcut	0.79	2.55	1.32	3.55	0.03	0.13
4—clearcut	0.96	2.48	1.50	3.40	0.02	0.09
5—clearcut/buffer	0.39	1.51	0.94	2.92	0.02	0.09
6—clearcut	0.23	1.35	0.81	4.10	0.02	0.16
8 and 9—controls	0.23	1.21	0.71	2.86	0.02	0.12
C—control (upstream)	0.27	1.02	0.67	4.20	0.01	0.04

Source: Stuart and Dunshie 1976.

Study X.B.5

Leading Ridge Watershed 2, Pennsylvania State University

Silvicultural treatment: Forty-six percent of the watershed was successively clearcut and herbicided. The sequence of operation was (1) winter of 1966-67—21.3 ac (9 ha) of the lower watershed were clearcut; (2) summers of 1967, 1968, and 1969 — stumps were treated with herbicide to control stump sprouting; (3) winter of 1971-72 — 2.70 ac (1.0 ha) of the middle watershed were clearcut; and (4) both clearcuts treated with herbicide in June 1974.

Vegetation: Uneven-aged oak, hickory, and maple.

Drainage: Treatment, Leading Ridge Watershed (LR) 2,106 ac (42 ha) with 48.3 ac clearcut.
Control, Leading Ridge Watershed 1, 303 ac (121 ha).
Control, Leading Ridge Watershed 3, 257 ac (100 ha).

Sampling: Weekly sampling for nutrient concentrations in streamflow began in 1972.

Results:

Date	Control LR-1	Treatment LR-2 NO_3-N	Control LR-3
		mg/l	
Oct. 1972-Sept. 1973	Clearcutting had no apparent effect		
Oct. 1973-May 1974	0.02	0.10	0.01
June 1974-Dec. 1974	0.04	2.08	0.08
June-Aug. (ave max)		0.4	
Sept.-Dec. (ave max)		5.0	
Sept.-Dec. (max measured)		8.4	

Source: Corbett and others 1975.

Study X.B.6
Fernow Experimental Forest,
West Virginia

Silvicultural treatment:	Watershed 3 was clearcut 1969. Watershed 4 was undisturbed and used as a control. Watershed 2 was subjected to a diameter-limit cut in August 1972.
Vegetation:	Mixed deciduous — oaks, maples, yellow poplar, black cherry and beech.
Drainage:	Watershed 3, 84 ac (34 ha). Watershed 4, 94 ac (38 ha). Watershed 2, 38 ac (15 ha).
Sampling:	Weekly sampling, May 1970-April 1971, Watersheds 3 and 4. Weekly sampling, Aug. 1972-Sept. 1974, Watershed 2.

Results:

Watershed	NO_3^-–N		NH_4^+–N	PO_4^{-3}
	Mean	Max	Mean	Ave
	mg/l			
Watershed 4				
1970 growing season	0.32	—	0.48	0.04
1970-71 dormant season	0.10	—	0.13	0.02
Watershed 3				
1970 growing season	0.18	0.59	0.35	0.07
1970-71 dormant season	0.49	1.42	0.14	0.04
Watershed 2				
Growing season				
Pre-silvicultural activity	0.2			
Post-silvicultural activity	0.6			
Dormant season				
Pre-silvicultural activity	Values unchanged			
Post-silvicultural activity	Values unchanged			

Sources: Aubertin and Patric 1972; Aubertin and Patric 1974; Patric and Aubertin 1976.

Study X.B.7

Coweeta Hydrologic Laboratory,
North Carolina

Silvicultural treatment:

Watershed No.	
1	All trees and shrubs cut 1956-57, no products removed; white pine planted 1957, 40 ac (16.2 ha).
2	Control, mixed mature hardwoods, 30 ac (12.1 ha).
6	Cut 1958 and products removed; lime added, fertilized, and grassed in 1959; refertilized 1965; herbicided 1966 and 67, 22 ac (8.9 ha).
14	Control, mixed mature hardwoods, 151 ac (61.1 ha).
13	All trees and shrubs cut 1936, recut 1962; no products removed, 40 ac (16.2 ha).
18	Control, mixed mature hardwoods, 31 ac (12.5 ha).
17	All trees and shrubs cut 1942; recut annually through 1955, no products removed; white pine planted in 1956, 33 ac (13.4 ha).
21	Control, mixed mature hardwoods, 60 ac (24.3 ha).
28	All trees and shrubs cut on 190 ac (77 ha); cove hardwoods thinned on 96 ac (39 ha); no cutting on 69 ac (28 ha); products removed 356 ac (144.1 ha).
32	Control, mixed mature hardwoods, 102 ac (41.3 ha).
37	All trees and shrubs cut in 1963; no products removed, 108 ac (43.7 ha).
34	Control mixed mature hardwoods 81 ac (32.8 ha).

Vegetation:	See "Silvicultural treatment," above.
Drainage:	See "Silvicultural treatment," above.
Sampling:	May 1972-April 1973.

Results:

Watershed[1]	NO_3^-–N		NH_4^+–N		PO_4^{3-}–P	
	Mean	Max	Mean	Max	Mean	Max
	mg/l					
1	0.029	0.077	0.003	0.020	0.006	0.022
2	0.004	0.017	0.002	0.020	0.006	0.020
6	0.619	1.230	0.004	0.010	0.007	0.030
14	0.004	0.024	0.004	0.031	0.005	0.017
13	0.044	0.084	0.003	0.014	0.004	0.013
18	0.003	0.014	0.004	0.022	0.005	0.018
17	0.154	0.249	0.004	0.012	0.012	0.336
21	0.003	0.016	0.004	0.024	0.004	0.029
28	0.094	0.208	0.003	0.017	0.004	0.020
32	0.003	0.015	0.003	0.013	0.004	0.013
37	0.149	0.246	0.004	0.036	0.006	0.095
34	0.002	0.019	0.003	0.024	0.006	0.019

[1] Watersheds listed below are alternated treated and controlled (1—treated, 2—control) for comparison. Refer to "Silvicultural treatment" for details.

Sources: Douglass and Swank 1975; Swank and Douglass 1975.

Study X.B.8

USAEC's Savannah River Plant,
Aiken, South Carolina

Silvicultural treatment:	Prescribed burn of surface litter.
Vegetation:	Loblolly pine.
Drainage:	Approximately 450 ac (180 ha).
Sampling:	Ground water samples were taken at control and burned areas 5 weeks after burn.

Results: Ground water.

Sample area	NO_3–N Mean	NO_3–N Std error	PO_4^{3}–P Mean	PO_4^{3}–P Std error
	mg/l	mg/l	mg/l	mg/l
Burned	0.007	0.0005	0.0047	0.0012
Control	0.006	0.0009	0.0040	0.0010

Source: Lewis 1974.

Study X.B.9

Grant Memorial Forest,
[redacted] Georgia

Silvicultural treatment:	77 ac were clearcut beginning in October 1974. Harvesting and site preparation (roller chopping) was completed in December 1975. The site was planted in January 1976. An adjacent untreated watershed was monitored as a control.
Vegetation:	Old field Loblolly pine.
Sampling:	December 1973-January 1977 (approximately 200 weekly samples).

Results: (Mean conc. of all samples)

Watershed	NO_3–N	Total P
	mg/l	mg/l
Treated		
Calibration, Dec. 1973-Oct. 1974	0.058	0.210
Harvest and site prep., Nov. 1974-Dec. 1975	0.029	0.190
Following planting, Jan. 1976-Jan. 1977	0.028	[1]0.476
Control		
Calibration, Dec. 1973-Oct. 1974	0.149	0.216
Nov. 1974-Dec. 1975	0.113	0.230
Jan. 1976-Jan. 1977	0.108	[1]0.582

[1] Particularly high values of phosphorus occurred during September-October 1976. Although unexplained, it is important to note that both the treated and the control watersheds exhibited high values during this period.

Source: Hewlett 1977.

Study X.B.10

H. J. Andrews Experimental Forest,
Eugene, Oregon

Silvicultural treatment:	Patchcut using high-lead yarding; with 25 percent of the area cut, plus an additional 6 percent in roads. Clearcut entire drainage, but no roads were present. Harvesting operations were begun in the fall of 1962 and were completed in 1966. Both areas were broadcast burned following yarding. A third drainage was undisturbed and served as a control.
Vegetation:	Old-growth Douglas fir.
Drainage:	Patchcut, 237 ac (96 ha). Clearcut, 149 ac (60 ha). Control, 250 ac (101 ha).
Sampling:	119 samples were collected, usually during storm runoff, during the period April 1965-July 1968.

Results:

Clearcut

Date and treatment	NO_3–N		NH_4^+–N	PO_4^{3-}–P	
	Mean annual	Instantaneous max		Mean annual	Instantaneous max
	mg/l				
1966 (H)[1]	0.020	0.050	---	0.024	0.066
1967 (B)	0.050	0.066	0.110	0.039	0.121
1968 (R)	0.200	0.600	0.001	---	---
1971 (R)	0.046	0.065	---	0.036	0.050
1972 (R)	0.023	0.056	---	0.034	0.045

Maximum and mean maximum taken during a 12-day period after broadcast burning in 1967

Measurement	NO_3–N		NH_4^+–N		PO_4^{3-}–P	
	Clearcut	Control	Clearcut	Control	Clearcut	Control
	mg/l					
Maximum	0.60	---	7.60	---	0.13	---
12-day mean	0.43	0.01	1.19	0.001	0.05	0.05

Patchcut

Dissolved solids concentration increased as a result of harvesting. The effect lasted for 6 years and was no longer statistically different from the pre-silvicultural activity in 1968.

Control

Date and treatment	NO_3–N		NH_4^+–N	PO_4^{3-}–P	
	Mean annual	Instantaneous max		Mean annual	Instantaneous max
	mg/l				
1966 (U)	0.010	---	---	0.026	---
1967 (U)	0.003	---	0.003	0.016	---
1968 (U)	0.001	---	<0.001	---	---
1971 (U)	0.0003	---	---	0.032	---
1972 (U)	0.0015	---	---	0.016	---

[1] H = harvested, B = burned, R = revegetating, and U = undisturbed.

Source: Fredriksen 1971; Fredriksen 1977; Fredriksen and others 1975; Rothacher and others 1967.

Study X.B.11
Bull Run Watershed,
Portland, Oregon

Silvicultural treatment: Clearcut on 25 percent of watersheds — the slash on one was burned and left to decompose on the other. On the burned watershed, harvesting was done the summer of 1969 and the slash was burned in the fall of 1970. On the unburned watershed, two seasons (1971 and 1972) were required to completely fell the units; harvesting was completed summer of 1973. The untreated watershed served as a control.

Vegetation: Old-growth Douglas fir.

Drainage: Fox Creek: Clearcut and burned, 145 ac (59 ha).
Clearcut and not burned, 175 ac (71 ha).
Control, 625 ac (253 ha).

Sampling: Sampling began April 1970. Proportional samples taken over 3-week intervals throughout each year.

Results:

Year and treatment	NO_3-N Mean annual	NO_3-N Max	NH_3-N Mean annual	NH_3-N Max	Dissolved organic N Mean annual	Dissolved organic N Max	Total phosphorus Mean annual	Total phosphorus Max
	mg/l							
Clearcut								
1970 (H)[1]	0.012	0.019	0.003	0.020	0.037	0.058	0.035	0.065
1971 (B)	0.027	0.079	0.005	0.100	0.036	0.049	0.027	0.055
1972 (R)	0.046	0.056	0.001	0.022	0.040	0.062	0.014	0.030
1973 (R)	0.034	0.057	0.001	0.090	0.036	0.058	0.028	0.100
1974 (R)	0.045	0.064	---	---	0.043	0.133	0.011	0.093
1975 (R)	0.023	0.034	---	---	0.043	0.075	0.016	0.032
1976 (R)	---	0.033	---	---	---	0.051	---	0.025
Clearcut—Not Burned								
1970 (U)	0.002	0.014	0.002	0.005	0.036	0.078	0.028	0.070
1971 (F)	0.004	0.017	0.005	0.089	0.038	0.096	0.032	0.055
1972 (F)	0.014	0.030	0.001	0.010	0.029	0.046	0.013	0.045
1973 (H)	0.022	0.042	0.003	0.036	0.032	0.042	0.021	0.030
1974 (R)	0.080	0.115	---	---	0.032	0.082	0.011	0.062
1975 (R)	0.093	0.114	---	---	0.044	0.076	0.020	0.046
1976 (R)	---	0.066	---	---	---	0.066	---	0.030
Control								
1970 (U)	0.006	0.027	0.005	0.013	0.045	0.063	0.040	0.065
1971 (U)	0.003	0.020	0.004	0.078	0.043	0.064	0.032	0.070
1972 (U)	0.005	0.040	0.002	0.018	0.036	0.070	0.014	0.080
1973 (U)	0.013	0.056	0.002	0.007	0.038	0.062	0.024	0.100
1974 (U)	0.002	0.053	---	---	0.034	0.081	0.013	0.090
1975 (U)	0.002	0.028	---	---	0.050	0.068	0.015	0.033
1976 (U)	---	0.040	---	---	---	0.065	---	0.031

[1] H = harvested; B = burned; F = felled; R = revegetating, and U = undisturbed

Source: Fredriksen 1977.

Study X.B.12

South Umpqua Experimental Forest,
50 kilometers ESE of Rosberg, Oregon

Silvicultural treatment:	Shelterwood harvest — 50 percent of the area removed; small clearcut — 30 percent of the area in 20 small clearcuts from 0.6 - 1.4 ha (3.1 ac); complete clearcut — all trees removed. Logging residue on watersheds was piled and burned. Roads were constructed June-September 1970 and harvesting done June-September 1971.
Vegetation:	Mixed conifer.
Drainage:	Coyote Creek: Shelterwood, 171 ac (69 ha). Complete clearcut, 123 ac (50 ha). Small clearcut, 169 ac (68 ha). Control, 120 ac (49 ha).
Sampling:	Sampling began October 1, 1969. Proportional samples taken over 3-week intervals throughout each year.

Results:

Year and treatment	NO_3-N mean annual mg/l	NO_3-N max mg/l	NH_4-N mean annual mg/l	NH_4-N max mg/l	Disolved organic N mean annual mg/l	Disolved organic N max mg/l	Total-P mean annual mg/l	Total-P max mg/l	Ortho-P mean annual mg/l	Ortho-P max mg/l
Shelterwood										
1970 (U)[1]	0.001	0.005	0.002	0.027	0.077	0.165	0.032	0.080	0.015	0.030
1971 (RC)	0.002	0.016	0.002	0.010	0.048	0.126	0.052	0.090	0.020	0.033
1972 (H)	0.004	0.012	0.003	0.009	0.075	0.114	0.043	0.095	0.028	0.070
1973 (R)	0.003	0.033	0.005	0.015	0.039	0.060	0.048	0.115	0.014	0.090
1974 (R)	0.001	0.017			0.051	0.155	0.030	0.076	0.015	0.021
1975 (R)	0.004	0.019			0.067	0.151	0.038	0.069	0.016	0.021
Complete Clearcut										
1970 (U)	0.001	0.009	0.001	0.020	0.093	0.142	0.048	0.150	0.048	0.100
1971 (U)	0.005	0.018	0.002	0.010	0.064	0.132	0.086	0.133	0.051	0.115
1972 (H)	0.002	0.007	0.003	0.008	0.080	0.178	0.062	0.140	0.054	0.062
1973 (R)	0.126	0.178	0.018	0.043	0.084	0.252	0.100	0.205	0.064	0.112
1974 (R)	0.242	0.365			0.104	0.176	0.068	0.130	0.054	0.082
1975 (R)	0.275	0.510			0.123	0.161	0.091	0.148	0.060	0.092
Small Clearcut										
1970 (F)	0.003	0.022	0.003	0.031	0.105	0.149	0.034	0.090	0.016	0.038
1971 (RC)	0.055	0.177	0.001	0.004	0.073	0.142	0.032	0.049	0.013	0.026
1972 (H)	0.004	0.031	0.001	0.005	0.081	0.120	0.035	0.070	0.031	0.045
1973 (R)	0.026	0.120	0.009	0.034	0.056	0.142	0.038	0.090	0.011	0.021
1974 (R)	0.007	0.087			0.070	0.138	0.023	0.058	0.011	0.018
1975 (R)	0.019	0.059			0.084	0.121	0.034	0.077	0.011	0.022
Control										
1970 (U)	0.001	0.004	0.001	0.006	0.105	0.185	0.036	0.118	0.025	0.080
1971 (U)	0.005	0.025	0.003	0.012	0.058	0.133	0.060	0.200	0.029	0.114
1972 (U)	0.003	0.005	0.002	0.006	0.078	0.095	0.045	0.060	0.039	0.045
1973 (U)	0.002	0.034	0.014	0.061	0.124	0.057	0.053	0.110	0.025	0.045
1974 (U)	0.004	0.022			0.072	0.132	0.036	0.069	0.024	0.033
1975 (U)	0.004	0.034			0.089	0.137	0.049	0.071	0.024	0.026

[1] U-undisturbed, F-fertilized, H-harvest, RC-road construction R-revegetating

Source: Fredriksen 1977.

Study X.B.13

Alsea Basin, Oregon Coast Range

Silvicultural treatment:	Needle Branch was completely clearcut beginning in March 1966; logging slash was burned (very hot fire) in October 1966. Deer Creek was 25 percent clearcut in three logging units. Only one unit in Deer Creek was burned (light burn). Flynn Creek remained untreated and served as the control.
Vegetation:	Douglas fir and alder. Alder was predominant species on Flynn Creek (68%) and Deer Creek (68%). Douglas fir predominated on Needle Branch (80%).
Drainage:	Needle Branch, 175 ac (70.68 ha). Deer Creek, 750 ac (303.32 ha). Flynn Creek, 500 ac (203.14 ha).
Sampling:	2 years before and 2 years after logging.

Results:

Watershed and treatment	Water year	NO_3-N		Total phosphate P	
		Max observed	Yearly mean	Min	Max
		mg/l			
Needle Branch Clearcut	1965	0.20	0.12	0.01	0.10
	1966	0.70	0.19	0.01	0.10
	1967	2.10	0.44	0.01	0.10
	1968	1.65	0.43	0.01	0.10
Deer Creek[1] Patchcut	1965	3.17	1.12	0.01	0.10
	1966	2.10	0.98	0.01	0.10
	1967	2.70	1.21	0.01	0.10
	1968	2.40	1.12	0.01	0.10
Flynn Creek[1] Control	1965	3.19	1.21	0.01	0.10
	1966	2.18	1.16	0.01	0.10
	1967	2.70	1.18	0.01	0.10
	1968	2.20	1.18	0.01	0.10

[1] High nitrate-N values probably due to alder.

Source: Brown and others 1973.

Study X.B.14

Bitterroot National Forest, Montana

Silvicultural treatment: Three watersheds were clearcut and three paired watersheds were used as controls. Lodgepole Creek was 97 percent clearcut, most of it in 1969 and 1970. Mink Creek was 83 percent clearcut in 1968 and dozer piled in 1971. The lower 46 percent of Little Mink Creek was clearcut in 1963, dozer piled in 1971, burned in 1972, and planted in 1973.

Vegetation: Mixed coniferous, ponderosa pine, Douglas fir, lodgepole pine, Engelmann spruce, and subalpine fir.

Drainage:

1. Lodgepole Creek, treatment, 497 ac (201 ha).
1. Spruce Creek, control, 467 ac (189 ha).
2. Mink Creek, treatment, 614 ac (249 ha).
2. Springer Creek, control, 866 ac (350 ha).
3. Little Mink Creek, treatment, 103 ac (41 ha).
3. Little Mink Creek, control, 152 ac (61 ha).

Sampling: One year from October 1, 1972-September 30, 1973.

Results:

Watershed	NO_3-N Mean annual mg/l	Watershed	NO_3-N Mean annual mg/l
1. Lodgepole Creek	0.19	2. Springer Creek	0.13
1. Spruce Creek	0.11	3. Little Mink Creek	0.40
2. Mink Creek	0.17	3. Little Mink Creek	0.17

Source: Bateridge 1974.

Study X.B.15

Priest River Experimental Forest, Idaho

Silvicultural treatment:	Three watersheds were treated. Benton Creek was clearcut in 1969, with a waterside area remaining along stream, and broadcast burned in 1970. Ida Creek was clearcut in 1970, with waterside area, and the slash was windrowed and burned. Canyon Creek was also clearcut with a waterside area, and broadcast burned.
Vegetation:	Mixed conifers, western white pine, western red cedar, Douglas fir, and western larch.
Drainage:	Not defined.
Sampling:	Benton Creek, September 1970 to June 1972. Ida Creek, October 1970 to June 1972.

Sampling was done above and below the silvicultural operation.

Results:

Watershed	[1]NO$_3$-N		Watershed	NO$_3$-N	
	Mean	Std error		Mean	Std error
	mg/l				
Benton			Canyon		
Control	0.20	0.05	Control	0.09	0.02
Treatment	0.18	0.02	Treatment	0.05	0.01
Ida			Precipitation		
Control	0.14	0.02		0.09	0.01
Treatment	0.16	0.02			

[1] NO$_3$-N values are higher than normally expected due to the minimum detection (0.14 mg/l).

Source: Snyder and others 1975.

Study X.B.16
Marcell Experimental Forest, Minnesota

Silvicultural treatment:	62.5 ac of aspen uplands were clearcut between December 1970 and January 1972.
Vegetation:	Aspen/birch and black spruce (bog).
Drainage:	Treatment, 84 ac (34 ha). Control, 130 ac (52 ha).
Sampling:	Pre-silvicultural activity samples (9) were taken in the spring, summer and fall. Post-silvicultural activity sampling (26 samples) was concentrated during high flows.

Results:

Sampling	Organic -N		NH_4 N		NO_3 N		Total -N		Total PO_4	
	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error	Mean	Std error
	mg/l									
Silvicultural-activity										
Pre-	0.93	0.19	0.35	0.10	0.31	0.12	1.69	0.18	0.15	0.03
Post-	0.80	0.07	0.55	0.11	0.16	0.06	1.50	0.13	0.17	0.03
Control										
Pre-	0.92	0.16	0.25	0.03	0.30	0.10	1.48	0.14	0.13	0.01
Post-	0.85	0.07	0.41	0.06	0.12	0.01	1.39	0.07	0.12	0.02

Source: Verry 1972.

Study X.B. 17

West Central Alberta,
Canada

Silvicultural treatment:	Clearcutting progressively over 13 forest watersheds located in 3 working circles (management units).
Vegetation:	Lodgepole pine, white spruce, and aspen.
Drainage:	Ranged in size from 1,725 to 5,914 acres (700 to 2,400 ha).
Sampling:	Summer 1974, 117 samples during spring snowmelt and 104 samples during summer recession period.

Results:

		NH_4^+		NO_3		PO_4^{3-}-P	
		Mean	Std error	Mean	Std error	Mean	Std error
		mg/l					
Marlboro Circle							
2 controls	May-June	0.52	0.07	0.04	0.02	0.011	0.001
	July-Aug.	0.22	0.03	0.006	0.0002	0.007	0.001
2 treated	May-June	0.68	0.09	0.02	0.01	0.012	0.001
	July-Aug.	0.18	0.02	0.006	0.001	0.008	0.001
Berland Circle							
2 controls	May-June	0.39	0.05	0.011	0.003	0.010	0.001
	July-Aug.	0.10	0.01	0.004	0.001	0.005	0.003
2 treated	May-June	0.34	0.06	0.047	0.009	0.008	0.0005
	July-Aug.	0.09	0.02	0.028	0.004	0.004	0.0001
McLeod Circle							
2 controls	May-June	0.48	0.03	0.010	0.002	0.012	0.001
	July-Aug.	0.20	0.03	0.008	0.002	0.006	0.0003
2 treated	May-June	0.48	0.03	0.016	0.003	0.009	0.001
	July-Aug.	0.22	0.03	0.005	0.001	0.005	0.0005

Source: Singh and Kalra 1975.

Study X.B.18

Dennis Creek, Okanagan Valley,
British Columbia

Silvicultural treatment:	Clearcutting 383 ac (155 ha) representing about 25 percent of the drainage area.
Vegetation:	Engelmann spruce-subalpine fir.
Drainage:	Dennis Creek treatment, 2,370 ac (960 ha). James Creek control, 2,000 ac (810 ha).
Sampling:	Sampling was done at two sites each above and below the silvicultural operation and on an adjacent undisturbed watershed.

Results:

	Total Kjeldahl nitrogen			NO_3-N			Total phosphorus		
	Min	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
	mg/l								
Below cut									
Site 1	0.090	0.189	0.351	0.002	0.003	0.010	0.005	0.015	0.036
Site 2	0.090	0.242	0.596	0.002	0.028	0.368	---	---	---
Above cut									
Site 1	0.095	0.166	0.346	0.002	0.004	0.013	0.002	0.010	0.031
Site 2	0.095	0.191	0.416	0.002	0.010	0.050	---	---	---
Control									
Site 1	0.100	0.308	0.448	0.002	0.015	0.040	0.014	0.028	0.056
Site 2	0.100	0.328	0.467	0.002	0.029	0.124	---	---	---

Source: Hetherington 1976.

Chapter XI

INTRODUCED CHEMICALS

this chapter was prepared by the following individuals:

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INTRODUCTION

Chemicals have played an important role in the success story of modern American agriculture. These same management tools — fertilizers, insecticides, herbicides, fungicides, rodenticides, avicides, piscicides, etc. — are equally important in meeting the rapidly growing demand for forest products. Their magnitude, intensity, and pattern of use is vastly different in forestry, and these chemicals provide an economically feasible means of controlling insects and disease and increasing timber production. However, their widespread use cannot proceed without adequate consideration of the potential impacts upon environmental quality. The forest land manager has a responsibility to protect the environment from contamination and thus must be aware of the potential hazards involved with each silvicultural practice that uses chemicals.

Chemicals introduced into a watershed as part of a silvicultural activity represent a potential non-point source of pollution for forest streams. Research findings and a long history of use have established that most forest chemicals offer minimum potential for degradation of the aquatic environment when they are used properly (Norris and Moore 1976). This chapter discusses the types of fertilizers and pesticides used, the magnitude and scope of chemical use, the behavior of chemicals in the forest environment, and the mechanisms by which chemicals may reach forest streams. This information forms the basis for understanding the non-point source pollution processes that result from chemicals used in silvicultural activities and for selecting effective controls. There is insufficient data to permit us to quantify control effectiveness.

DISCUSSION

MAGNITUDE AND SCOPE OF CHEMICAL USE

Newton and Norgren (1977) have categorized the chemicals used in forest management into three general groups based upon the broad objectives of their use. One group is herbicides which are used when forest productivity is to be focused on selected species. Herbicides do not influence the basic productivity of the forest ecosystem, but are used to channel that productivity into selected timber species that have special value. The second group of chemicals, including insecticides and rodenticides, is used to reduce losses of important tree species. The specific targets of these chemicals are insect and animal pests that are capable of damaging or destroying commercially desirable tree species. Fungicides used to control diseases in existing stands are also included in this group. The behavior of these two major groups is discussed together as "pesticides" in this publication. The third group of chemicals includes only fertilizers. Chemicals in this category are used to increase growth rates of commercial tree species by raising the overall productivity of forest ecosystems. Fertilizer chemicals also are used as fire retardants and will be included in this group rather than discussed separately. A wide variety of other chemicals are used in forestry for insect and disease control in nurseries, for soil stabilization, for dust control, for road surfacing, and various other purposes. However, these latter chemical uses are limited in scope and will not be discussed in this publication.

The potential impact of introduced chemicals upon forest water quality depends largely on the chemical and its pattern of use. In intensive agriculture, chemicals may be applied one or more times during a crop cycle. Crop cycles are short; thus, regular and repeated applications are a common practice. By contrast, most forest land will not be treated with chemicals at any time during a crop cycle. Lands that are treated seldom receive more than one treatment in a crop cycle. (Crop cycles range from 20 to more than 100 years.) A large number of chemical compounds are registered for use in agriculture, while in forestry less than 15 principal pesticides are used. Forestry practices account for only slightly more than 1 percent of the total pesticide use and less than 1 percent of the total fertilizer consumption in the United States.

Pesticides

Pesticide use on forest lands between July 1, 1975, and September 30, 1976, is summarized in table XI.1. The figures represent both pesticides used by the Forest Service and pesticides used on projects involving Federal assistance provided by the Forest Service (USDA 1977). In general, these figures underestimate the total use in forestry because they do not include pesticide use by other Federal land management agencies or by various State and private groups. In addition, data presented for insecticide use have been modified by deducting the figures for one large project conducted to control defoliation caused by the Eastern spruce budworm. This single insect control project accounted for 85 percent of the total figure for

Table XI.1.—Pesticide use in forests, July 1, 1975, to September 30, 1976[1]

Pesticide used	Acres treated	Percent	Pounds used[2]	Percent
Herbicide	235,551	38	563,517	62
Insecticide	326,148	53	[3]192,175	21
Fungicide	34,109	5	143,431	16
Rodenticide	22,599	4	6,053	1
Piscicide	481	0	833	0
Bird repellent	714	0	289	0

[1] Reporting period is 15 months, FY 1976 and Transition Quarter (USDA 1977).

[2] Reported as pounds of active ingredients.

[3] Data presented do not include 3,501,950 acres treated with 2,663,208 pounds of insecticide chemicals to control defoliation caused by the Eastern spruce budworm. These data were omitted in order to provide a closer approximation of the annual pesticide use pattern.

treated land area and 75 percent of the total figure for applied pesticide chemicals during the 15-month period covered by the report. Large control projects of this magnitude (3,501,950 ac) do not occur on an annual basis; therefore, the data were modified as described in order to provide a closer approximation of the annual pesticide use pattern.

Most insecticides applied to forests in the United States are applied to Forest Service and adjacent lands through Federal cooperative insect control projects for which the Forest Service has responsibility. Thus, the figures presented in table XI.1 provide a fairly close estimate of the total annual use of insecticides. Herbicide use projects are carried out independently by the various forest land management groups, and the figures presented reflect a considerable underestimate of total herbicide use. It is apparent, however, that herbicide use is considerably greater than insecticide use in terms of the amount of chemical applied, and probably exceeds insecticide use in terms of total area treated annually (with the exception of large insect control projects).

To further illustrate the scope of pesticide use in forests, a list of individual pesticide compounds or combinations is presented in table XI.2. The land area treated with each pesticide provides an indication of its importance in forest land management. Data presented were obtained from the Fiscal Year (FY)-1976 and Transition Quarter Pesticide-Use Report (USDA 1977) and essentially represent annual usage. The total number of pesticide chemicals or combinations is quite large, but the major applications employ only a few. Seven herbicide chemicals account for 95 percent of the total herbicide use.

These figures indicate that approximately 0.2 percent of the commercial forest land in the United States is treated with pesticides in any given year (0.8 percent in FY-1976 including the large Eastern spruce budworm spray program). Therefore, interaction between pesticides and water quality is not an extensive problem. In those areas treated with pesticides, however, the interaction, although localized, can be intense.

Table XI.2—Reported pesticides used for silviculture in the United States, July 1, 1975, to September 30, 1976.[1]

Herbicides	Acres treated	Herbicides	Acres treated	Insecticides	Acres treated
2,4-D	79,713	Cacodylic Acid	688	Carbaryl	[2]74,036
2,4,5-T	40,155	Methyl Bromide	605	Lindane	65,076
2,4-D & Picloram	36,662	Dacthal	473	Trichlorfon	[2]58,705
Picloram	29,891	Amitrol	412	Malathion	50,488
2,4-D & 2,4,5-T	12,797	Trichlorobenzoic Acid	354	DDT	[3]6,875
MSMA	7,624	Trifluralin	227	Acephate	[2]5,900
2,4-D & 2,4-DP	6,073	Ureabor	200	Dibrom	3,000
Simazine	5,424	Ammonium Sulfamote	194	Difluron	[2]1,800
Simazine and Atrazine	3,000	Pentachlorophenol	190	Mirex	1,674
Atrazine	2,440	Bromacil	166	Bacillus Thuringiensis	[2]950
Diphenamid	1,673	Prometryne	156	Crotoxyphos	900
Mineral Spirits	1,219	Glyphosate	146	Dimethoate	851
Dalapon	1,215			Azinphos Methyl	681
2,4,5-TP (Silvex)	1,198			Methomyl	450
Dicamba	981			Dursban	368
2,4-D & Dicamba	950			Pyrethrins	300

---

[1] Compiled from U.S. Forest Service Pesticide Use Reports, the amounts include chemicials used by the Forest Service and chemicals used on projects involving Federal assistance by the Forest Service (USDA 1977). Actual total amounts are considerably greater.

[2] Does not include amounts used to control Eastern spruce budworm.

[3] DDT and Carbaryl were used for plague control.

Fertilizers

Fertilizers are applied annually to only a small portion of commercial forest lands. Levels of management on most forest lands have not yet reached the intensity where fertility would severely limit economic yields; however, several major forest industrial corporations and public agencies have been using forest fertilization as a standard management practice for a little over 10 years. Fertilization operations are restricted to the Pacific Northwest, where nitrogen deficiencies are commonly encountered, and to the Southeast, where phosphorous deficiencies often limit tree growth and reduce survival of young stands.

Fertilization of forest stands in the Pacific Northwest was initiated in 1965 when one industrial corporation aerially fertilized 1,500 acres of Douglas-fir with urea. Between 1965 and 1975, approximately 750,000 acres of Douglas-fir were fertilized in western Oregon and Washington (Moore 1975b, Norris and Moore 1976). Annual fertilization increased rapidly up to 1973 when 160,000 acres were treated in 1 year. The practice then dropped drastically as the energy crisis caused a shortage of fertilizer and also raised the price of nitrogen use to nearly double the cost per acre. Fertilization practice is increasing again now in the Pacific Northwest, but has not yet reached the earlier peak of annual fertilizer application.

The first forest fertilization project in the Southeast was conducted in 1963 on 630 acres (Groman 1972). The scope of operations in the Southeast has not approached that of the Northwest, but by 1971 approximately 110,000 acres had received chemical fertilizers. When a moderate, but steady, increase in the practice was assumed, a gross estimate of total fertilized acreage through 1975 was 350,000 acres.

Investigations conducted in the hardwood stands of the Northeast indicate that nitrogen deficiencies appear to be limiting growth, and the application of potassium has effectively stimulated growth on old fields that are being reforested. However, additional field research is needed before forest fertilization will be used in that region (Beaton 1973, Mader 1973d, Weetman and Hill 1973).

Fertilizers, like pesticides, are applied to a very small proportion of the total commercial forest land each year, and applications to any given site occur infrequently. Through 1975, the total acreage fertilized was only 0.2 percent of the commercial forest land in the United States, and the forested area fertilized in any one year did not exceed 250,000 acres. However, a much larger total acreage of commercial timber stands is considered potentially amenable to fertilization. The use of this practice to increase the volume of wood fiber produced per unit area, and over a shorter period of time, can be expected to increase.

Patterns Of Chemical Use

Insecticides

At present, there are very few insecticides registered for use on forest lands. Insect damage problems in recent years have been handled as special projects, where approval for a particular chemical or formulation is usually granted by regulatory agencies on a case-by-case basis. An environmental impact statement must be prepared for each project and is used as the basis for approval or denial of the proposed chemical control program.

The chlorinated hydrocarbon insecticides are not usually selected for use in forestry when alternate chemicals are available. The application of DDT in Idaho, Oregon, and Washington for control of the Douglas-fir tussock moth in 1974 was an exception. Insecticides more likely to be used in forestry are various organophosphate and carbamate compounds. Nonresidual biological control agents are also being used. Recent research has developed suspensions of insect disease cultures that are quite specific for the target insects. Virus cultures have been used in several projects with considerable success and low impact on nontarget terrestrial and aquatic insects. This material is now registered for use in the control of Douglas-fir tussock moth.

Applications of insecticides to forest areas are almost exclusively made by aerial spraying. Large or contiguous areas may be treated in a single project to control an outbreak of defoliating insects on commercially valuable timber. Regional projects may include a large part of an entire river drainage basin. Thus, in any one year, a large percentage of the total amount of a given insecticide applied to forests in the United States may be applied in only one region. Several to many years will normally elapse before an application of any magnitude is made again in the same region. While the potential for impact of insecticides on water quality and the aquatic community may be relatively widespread on a regional basis, it is still infrequent in occurrence.

Herbicides

Herbicidal chemicals are used for a wide variety of purposes in silvicultural activities including fuel break management; vegetation control on powerline, road, and railroad rights-of-way; conversion of hardwood brush to conifers; release of established conifers from hardwood brush competition; thinning; cull tree removal in established stands; and control of noxious weeds. The most commonly used chemicals are the phenoxy herbicides (2,4-D,2,4,5-T, and Silvex), picloram, and triazines (atrazine and simazine), and the organic arsenicals (MSMA and Cacodylic acid).

Herbicides are applied by a variety of means — aerial (rotary or fixed-wing aircraft), low pressure-high volume ground spray equipment, mist blowers, stem injection devices — and in a variety of forms — pellets, granules, and undiluted concentrates. Treatment areas are typically small (5 to 200 ac) and widely scattered. Large contiguous blocks are seldom treated. The annual extent of herbicide use remains reasonably constant on a regional basis; therefore, the opportunity for interaction between herbicides and streams occurs regularly, but is of limited scope in any one drainage system. Use of herbicides on any given site is usually limited to one or, at most, two applications.

Fungicides

Fungicidal chemicals receive intensive use in forest nurseries, but are seldom used in silvicultural activities. Nursery use is more comparable to agricultural use than to forestry use and is not included in this discussion. Fungicide treatments to stumps and roots for control of root and butt rots affect only small and isolated areas and provide little, if any, opportunity for impact on water quality.

Rodenticides

Rodenticide use has decreased sharply in recent years. The small quantities used in forestry and the methods of applying them to the ground indicate that any effects on water quality are not likely to be detectable.

Fertilizers

Forest fertilization is carried out in the Pacific Northwest by aerial application. Present operations are conducted almost exclusively with helicopters (Moore 1975b). In the Southeast and on Southern pine lands, ground equipment is used to fertilize young stands and aerial equipment makes application on older stands. Soils in Florida, the Flatwoods, and Atlantic Coastal Plain subregions are deficient in phosphorus and fertilizer is applied to them at time of planting or soon thereafter. Older stands respond to nitrogen or to nitrogen plus phosphate, if the stand is on a phosphorous deficient site (Bengston 1970).

Fertilizers may be applied to relatively large contiguous areas, but a more typical practice is to fertilize smaller management units in a patchwork fashion. Treated areas are usually some distance from users of potable or irrigation waters. The infrequency of application coupled with application to undisturbed forest soils and vegetation tends to minimize the potential for impact on water quality. Buffer strips can be maintained along major streams, but it is not possible to avoid all of the smaller headwater streams. Thus, some forest streams in a fertilized watershed will normally contain detectable amounts of chemical immediately after application.

CONCEPTS OF HAZARD AND CHEMICAL ACTION

Pesticides used in forest management are selected because of their known effects on specific targets. The hazard involved in their use is the risk of adverse effects on nontarget organisms. Two factors determine the degree of hazard: (1) the toxicity of the chemical and (2) the likelihood that nontarget organisms will be exposed to a toxic dose. Toxicity alone does not make a chemical hazardous. The hazard comes from exposure to toxic doses of that chemical. Even the most toxic chemicals pose no hazard if organisms are not exposed to them. Therefore, an adequate assessment of the hazard involved in the use of any chemical requires that both the likelihood of exposure and the toxicity of the chemical be considered (Norris 1971).

Chemical action is the direct effect of a chemical on an organism. Chemical action on any organism requires exposure and, furthermore, requires sufficient quantity of chemical present at the site of action, in an active form and for a sufficient period of time, to produce a toxic effect. There are two kinds of toxicity: acute and chronic. Acute toxicity is the fairly rapid response of organisms to one, or a few, relatively large doses of chemical administered over a short period of time. Chronic toxicity is the slow or delayed response of organisms that occurs after repeated or continuous exposure to small doses of chemical extending over a relatively long period of time. There are various gradations between these two extremes. The kind of response (acute or chronic) observed in nontarget organisms depends on the magnitude of the dose, the duration of exposure, and the behavior of the chemical.

Toxicity. — A consideration of the principles of toxicity or a review of the toxicity characteristics of silvicultural chemicals is beyond the scope of this chapter. Newton and Norgren (1977) provide an excellent summary of this topic. Reference sources for the more frequently used silvicultural chemicals are given in appendix XI.C.

Potential for exposure. — The potential for exposure of nontarget organisms is determined by the initial distribution of the chemical and its subsequent movement, persistence, and disposition in the environment. When a chemical is applied to a forested watershed, there is an interaction between the properties of the chemical and the properties of the environment. These interactions follow the basic laws of physics, chemistry, and biology and define chemical behavior (fig. XI.1). The resulting quantities of a chemical found in different parts of the environment at varying times after application determine the duration and magnitude of exposure of different organisms to the chemical. The overall impact of chemicals on both target and nontarget organisms and the selective action of chemicals depend on this exposure.

CHEMICAL BEHAVIOR OF PESTICIDES

The behavior of a chemical consists of its movement, persistence, and disposition in the environment. Such behavior determines how much chemical is in what part of the environment for what period of time and in what form. The initial distribution of a silvicultural chemical and its subsequent behavior in the terrestrial environment determines its potential role as a non-point source pollutant. Its behavior in the aquatic environment and its inherent toxicity determine its importance.

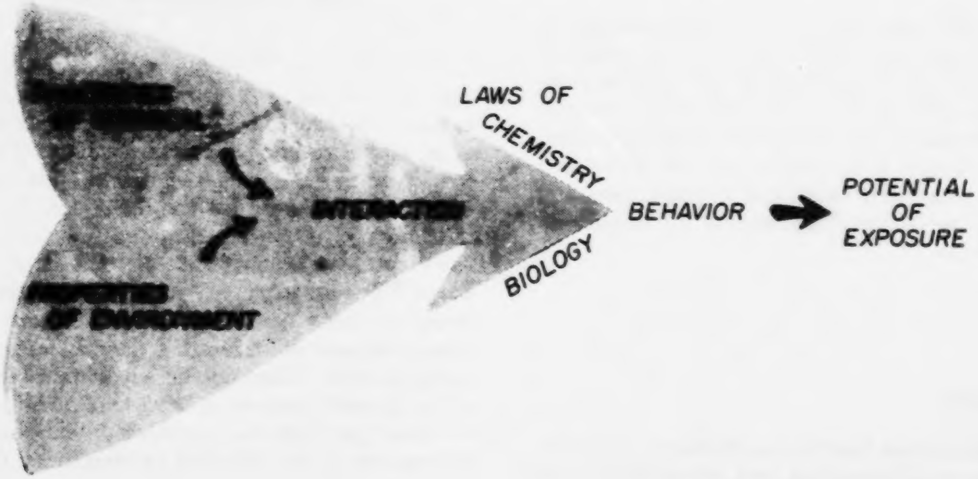

Figure XI.1.—The interaction of chemicals with the environment (Norris 1971).

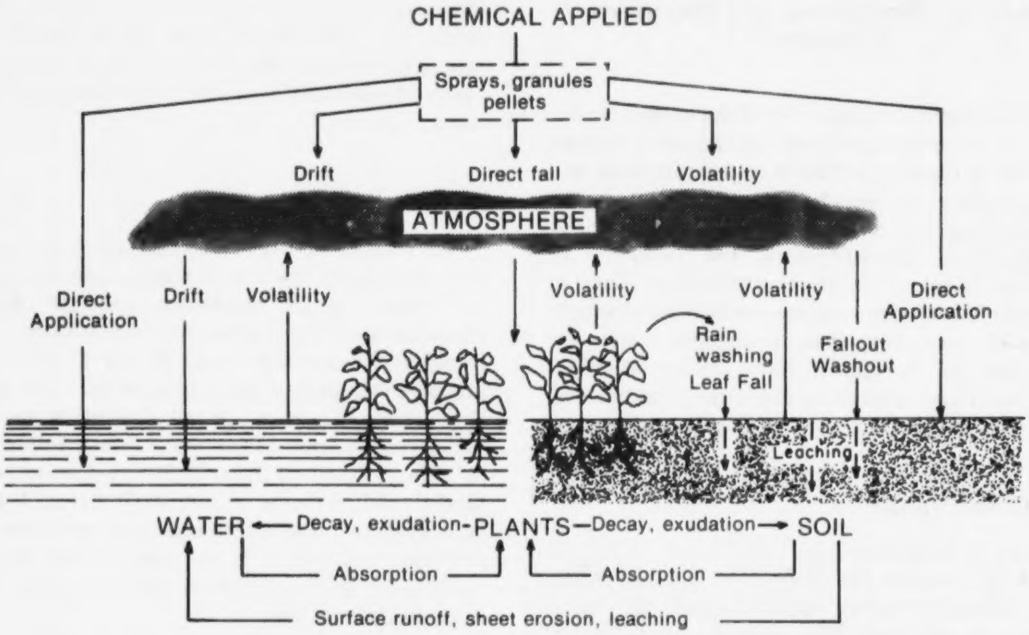

Figure XI.2.—The distribution and disposition of chemicals in the environment (Foy and Bingham 1969).

Initial Distribution Of Spray Materials

Aerially applied chemicals are distributed initially among four major components of the forest environment: air, vegetation, the forest floor, and surface waters (fig. XI.2). The amount of chemical entering each portion of the environment is determined by the chemical and equipment used and the environmental conditions that prevail at the time of spraying (Norris and Moore 1971).

Some spray material is dispersed by the wind as fine droplets called "drift." The degree of lateral movement of spray drift depends on droplet size, height of release, and wind velocity (fig. XI.3) (Reimer and others 1966). Additional amounts of chemical may remain in the air due to volatilization of spray materials while falling through the air. Most of the pesticide chemical not lost through drift or volatilization is intercepted by vegetation or the forest floor. Some small amount of pesticide may fall directly on surface waters.

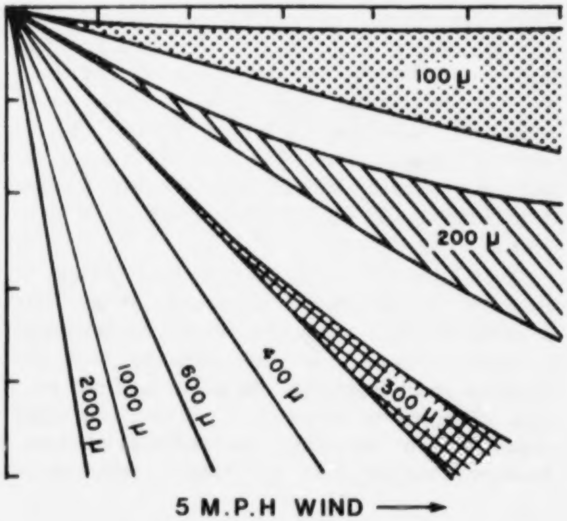

Figure XI.3.—Lateral movement of spray particles of various diameters falling at terminal velocity in an 8 km/hr crosswind (5 mph = 8 km/hr; 1 ft = 0.3048 m) (Reimer and others 1966).

Movement, Persistence, And Disposition Of Pesticides

The movement of pesticides includes movement within a given compartment of the environment (leaching in the soil profile) or movement from one compartment to another (washing pesticide residues from leaf surfaces to the forest floor by precipitation). Persistence is the tendency of pesticides to remain in an unaltered form. The disposition of pesticides concerns the various physical, chemical, and biological pathways taken by chemicals in becoming biologically harmless products. These aspects of chemical behavior will be discussed for each environmental compartment.

Distribution In Air

Losses of herbicides and insecticides to the air may be appreciable, but there is little quantitative data. During one test in western Oregon, for example, from 20 percent to 75 percent of a herbicide application did not reach the ground, but these results were confounded by the presence of nearby overstory vegetation[1]. Use of helicopters in place of fixed-wing aircraft and the introduction of improved drift control nozzles and spray additives have greatly reduced the amount of chemical reaching sites outside the target zone.

More recent work has used spray interception disks. Norris and others (1976b) reported 85 percent recovery of picloram and 70 percent recovery of 2,4-D when using the spray interception disks in a southern Oregon brush field that had been sprayed by helicopter. On four powerline rights-of-way in Oregon and Washington treated by helicopter with 2,4-D and picloram, interception disks recovered 71 percent of the 2,4-D and 90 percent of the picloram.

Several things can happen to that portion of chemical that becomes dispersed in the air. Fine droplets (drift) or vapors (volatiles) can be moved to other locations where they settle to the earth. Droplets and vapors can also be washed out with rain, absorbed or taken up by plants and other organisms, or adsorbed on various surfaces. Another possible fate for many pesticides is photodegradation (Moilanen and others 1975). With the exception of direct application or the deposition of spray drift, the air is not an important source of chemicals that later enter the aquatic environment.

Distribution In Vegetation

The amount of pesticide intercepted by vegetation depends on the rate of application, the nature and density of the vegetation, and the physical characteristics of the spray material. Chemicals intercepted by vegetation may be volatilized into the atmosphere, washed off by rain, or adsorbed on the leaf surface. There is limited absorption and very little translocation of many pesticides intercepted by foliage. Through the action of rain, much of the unabsorbed pesticide will be washed from the surface of the leaf. Pesticide remaining on the leaf surface and any pesticide not translocated to other plant parts will enter the environment of the forest floor during leaf fall.

Pesticides retained by the plant may be excreted back into the environment through the roots or they may end up in some plant storage tissue to be released at a later time. Through metabolic activity, plants may degrade a pesticide to nonbiologically active substances.

Studies of herbicides show that the highest concentrations of residue occur in foliage shortly after application (see table XI.3) (Morton and others

Table XI.3.—Residues of herbicide[1] in forage grass

Time after treatment (Weeks)	Herbicide residue		
	2,4-D[2]	2,4,5-T[2]	Picloram[3]
	------------------	ppm	------------------
0	100	100	135
1	60	60	---
2	50	30	32
4	30	15	---
8	6	6	24
16	1	2	16
52	---	---	3

[1] Rate of application equals 1.12 kg/ha.
[2] Data from figure 4 in Morton and others 1967.
[3] Data from table 5 in Getzendaner and others 1969.

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[1] *Newton, M., L.A. Norris, and J. Zavitkovski. Unpublished data on file Sch. For., Oregon State Univ., Corvallis.*

1967, Getzendaner and others 1969). A combination of factors causes the residue concentrations to decrease rapidly with time. Growth, dilution, weather, and metabolism of the herbicide by the plant are particularly important.

Weathering is very important in reducing residue levels of carbaryl on foliage. Wells (1966) reported that rain in excess of 1.8 inches (45 mm) falling 12 to 24 hours after spraying reduced initial residue levels of carbaryl on oak foliage from 190 ppm to about 15 ppm 3 days later. Degradation of carbaryl residues on plants is less important, but plants absorb only small amounts (Union Carbide 1968). Formulation also influences persistence of residues on foliage (Fairchild 1970). Carbaryl applied in an 80 percent wettable powder formulation had a half-life (the time required by an organism to eliminate, by biological or chemical processes, half the quantity of a substance taken in) of 3 to 4 days, while carbaryl applied in a Sevin-4-oil formulation was found to have a half-life of 8 to 10 days on range grasses. Typical initial residue levels on forest foliage ranged from 30 to 100 ppm immediately after treatment. These residues decreased to 5 to 20 ppm after 2 or 3 weeks (Back 1971).

Dylox (trichlorfon) insecticide is relatively nonpersistent; only small amounts remain on treated foliage beyond 1 week after application. Residue levels of 0.33 to 3.3 ppm trichlorfon on leaves, 0.42 to 1.1 ppm on twigs, and 1.5 ppm on forest litter 26 days after application were reported by Wilcox (1971). Residues were still detectable after 106 days, even though residues declined most rapidly over the first 7 days following spraying (Devine and Wilcox 1972). Weiss and others (1973) reported that Dylox residues dropped sharply within a few days after spraying, and that after 60 days, 15 percent of the initial level remained on leaves, 5 percent on the forest floor, and less than 1 percent in the soil.

Orthene, also an organophosphate insecticide, is readily degraded by plants. It has an observed half-life of from 5 to 10 days (Chevron 1973). This insecticide adheres to or is absorbed by leaf surfaces and washing of field-treated vegetation will remove no more than 5 percent of the residue present. Translocation from treated leaves to other parts of the plant is only very slight. Orthene is not persistent on forest vegetation because of its short half-life (Devine 1975). Following field applications at ¼, ¾, and 1½-lb active ingredient/acre, residues on leaves and in forest floor material declined to nondetectable levels in 1 to 2 months.

Distribution On The Forest Floor And In Soil

The forest floor is a major receptor of aerially applied spray materials. Pesticides on the forest floor may be volatilized and reenter the air, adsorbed on soil mineral or organic matter, leached through the soil profile by water, absorbed by plants, or degraded by chemical or biological means. Volatilization of chemicals from the soil surface may be responsible for the redistribution of fairly large amounts of some pesticides such as DDT and perhaps some phenoxy ester herbicides.

The length of time chemicals persist in the forest floor and soil bears strongly on the probability they will contaminate the aquatic environment. Pesticide degradation is usually biological, but chemical degradation is important in the loss of amitrole and the organophosphate insecticides (Hance 1967, Kaufman and others 1968, Norris 1970).

The common brush control herbicides (2,4-D, amitrole, 2,4,5-T, and picloram) are all degraded in the forest floor although their rates of degradation vary considerably (fig. XI.4). In red alder (*Alnus rubra*) forest floor material, 80 percent of the amitrole and 94 percent of the 2,4-D were degraded in 35 days, but 120 days were required to degrade 87 percent of the 2,4,5-T. Picloram degradation was slow, 35 percent in 180 days (Norris 1970).

Adsorption and leaching are processes which work in opposition to one another. Adsorbed molecules are not available for leaching, but adsorption is not permanent. The amount of pesticide that is adsorbed is in equilibrium with the amount of pesticide in the soil solution. As the concentration of pesticide in the soil solution decreases, more pesticide will be released from adsorption sites (fig. XI.5). Thus, adsorption provides only temporary storage, and the soil is, in effect, a reservoir of the chemical that will eventually be released. Leaching is a slow process, capable of moving pesticides only short distances (Harris 1967, 1969). Herbicides are generally more mobile in soil than insecticides, but mobility is relative, and even the movement of herbicides is usually measured in terms only of inches or a few feet.

Most of the chemicals applied to the forest, regardless of method of application, eventually reach the forest floor and soil compartments. Chemical behavior in this part of a forest watershed is particularly important because it determines whether these introduced chemicals will be immobilized, degraded, or transported to

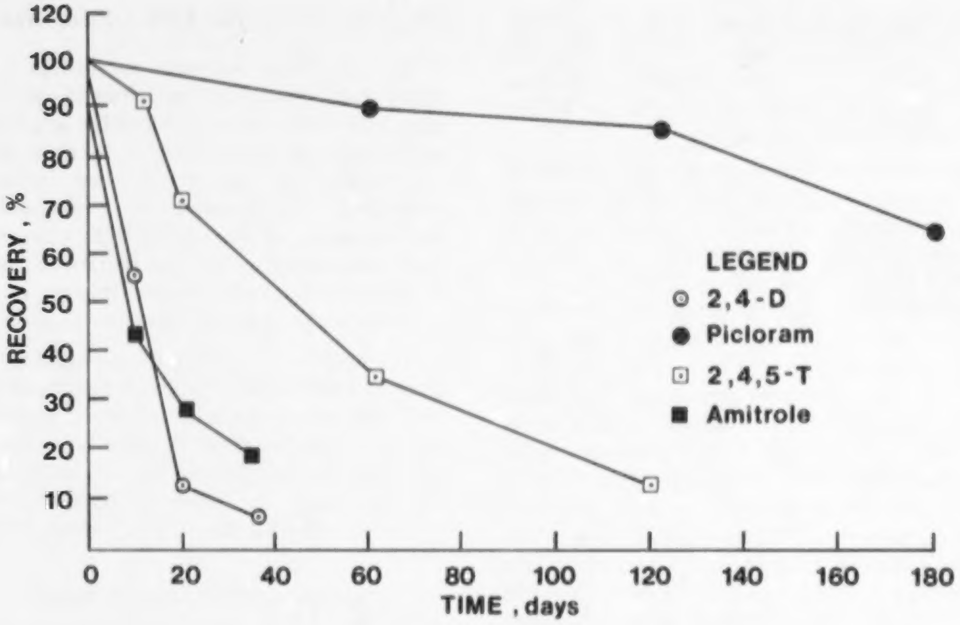


Figure XI.4.—Recovery of 2,4-D, amitrole, 2,4,5-T, and picloram from red alder forest floor material (Norris 1970).

$$\text{CHEMICAL} + \text{ADSORBENT} \underset{k_2}{\overset{k_1}{\rightleftharpoons}} \text{CHEMICAL : ADSORBENT}$$

Figure XI.5.—Chemical adsorption in soil is an equilibrium reaction.

the aquatic environment. The forest floor and soil make up a very active biological system that provides a number of processes by which pesticides can be destroyed, thus preventing their accumulation or redistribution. Each pesticide material, however, has its own chemical and physical properties that give it some degree of stability against degradation. Kearney and others (1969) have grouped the pesticides into major chemical classes and summarized their persistence in soil (fig. XI.6). Only the organochlorine insecticides have persistence times expressed in years. Persistence in the soil of all the other classes or groups of pesticides is measured in weeks or months. The length of each bar in figure XI.6. indicates the time required for 70 to 100 percent degradation of the particular pesticide when it was applied at normal rates. Data used to construct the graphs were obtained from studies conducted in agricultural soils, but the same pesticides used in forestry should have the same relative stability in forest soils. Some pesticides that are degraded by soil microbial activity persist for a shorter period of time in forest soils.

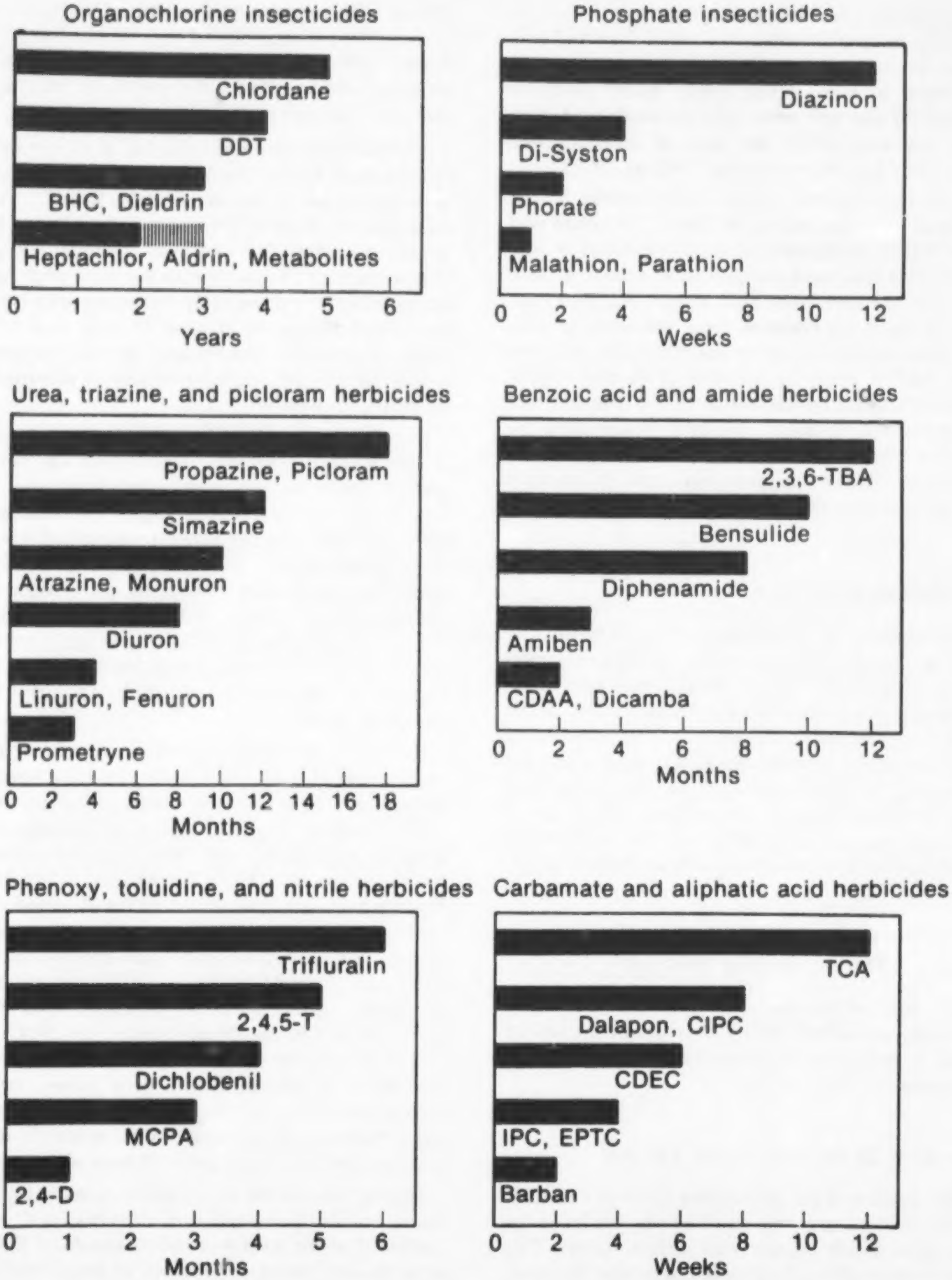


Figure XI.6.—Persistence of individual pesticides in soils (Kearney and others 1969).

Carbamate and organophosphate pesticides are relatively nonpersistent in the forest floor and soil. When Sevin-4-oil was applied at 1 pound carbaryl/acre to control the gypsy moth, pesticide residues in the soil were still detectable 64 days later, but were below the level of detection (0.2 ppm) 128 days after spraying (Wilcox 1972).

Dylox (trichlorfon) breaks down rapidly in the soil. In studies carried out in New York (Judd and others 1972), trichlorfon was not detected in any forest soil or lake mud samples after 4 days. Wilcox (1971), in another New York study, reported that after 14 days no residues were detected in soil. Malathion applied to soil persisted for 2 days in one study and 8 days in another (Pimentel 1971). Devine (1975) found that residues of Orthene in soil dissipated in 3 days. Studies conducted by Chevron Chemical Company (1973) on the persistence of Orthene in nine soils types indicated a half-life of 0.5 to 6 days when treated at 1 ppm.

Distribution In Surface Waters

Degradation of environmental quality in the forest is often first recognized by changes in stream quality. Stream contamination is a most important expression of environmental contamination in the forest because water is not only the habitat for many biological communities, but also a critical commodity to downstream users. Pesticides may enter streams by several pathways and forest managers can greatly influence the amount of chemical which enters streams near treated areas.

Entry Of Pesticides Into The Aquatic Environment

Any amount of pesticide that has not been degraded, adsorbed, volatilized, or taken up by plants is available to move into the aquatic environment.

Movement To Streams From The Air

That portion of the introduced chemical which is not lost as drift or intercepted by vegetation or the forest floor will fall directly on surface waters. This route of entry offers the greatest potential for short-term, but high-level, contamination of streams by pesticides in the forest environment. Stream contamination by herbicide residues from forest spray operations in Oregon has been intensively studied (Norris 1967, Norris and Moore 1971, Norris and Moore 1976, Norris and others 1976a, Norris and others 1976b, Norris and others 1977). Herbicide residues were found for short periods in all streams that flow through or by treated areas.

Although stream monitoring has been carried out in conjunction with numerous field applications of herbicides over a period of more than 10 years, measured residues of the phenoxy herbicides have never exceeded 0.1 mg/l in western Oregon. Concentrations of amitrole to 0.4 mg/l were found in one stream immediately below a spray unit in the Coast Range of Oregon (Norris and others 1966). Examples illustrating several important points about minimizing residues in streams are presented in appendix XI.A.

For a given rate of application, the concentration of herbicides in streams depends on the surface area of the stream in relation to its volume. The total amount of herbicide entering a stream varies with the length of the stream which receives the spray materials and with the location of the spray unit boundaries with respect to the stream. The highest concentrations of herbicide are found in streams originating in or flowing directly through spray units. In contrast, lowest concentrations are found in streams which are totally excluded from the spray area.

Surface water contamination caused by direct application of DDT was measured during and after forest spraying in eastern Oregon. The maximum DDT concentration (0.28 μg/l) was a sample taken a few hours after spraying. Most samples contained less than 0.01 μg/l DDT (Tarrant and others 1972). Endrin has also been found in forest streams following direct aerial seeding with endrin-coated Douglas-fir seed. The maximum concentration of 0.070 μg/l occurred immediately after seeding and decreased rapidly to below detection level (0.001 μg/l) within 5 hours (Moore and others 1974). At a second site in the same study, the maximum concentration of endrin found in a slower moving stream was 0.013 μg/l. However, residue concentrations decreased slowly and did not reach the detection limit of 0.001 μg/l until 10 days after seeding.

During insecticide application, some spray does reach small inconspicuous streams and small bodies of water such as shallow ponds or puddles even though direct application to larger bodies of water is avoided. Triclorfon has been found in small amounts in water samples collected immediately after spraying, but the concentration dropped below detectable limits 4 days after spraying (Judd and others 1972). In an outdoor pond trichlorfon had a half-life of 0.3 days (Chemagro 1971).

The movement of spray drift from treatment areas to surface waters is also an important source of pesticides in the aquatic environment, especially when large contiguous areas are sprayed. The amount of spray drift which occurs is influenced by the carrier, the size of the droplets, and the height of release. Wind speed, temperature inversions, relative humidity, and temperature are environmental factors which influence the droplet's size, rate of evaporation, speed of vertical descent, and, therefore, the extent of its lateral movement (Hass and Bouse 1968).

Movement To Streams From Vegetation

Only small amounts of pesticides will enter the aquatic environment from the washing action of rain on the vegetation that overhangs stream courses and from leaves falling into the water. Residues on buffer strip vegetation will normally be restricted to small amounts of chemical moved laterally as spray drift during application and volatile material brought down by precipitation. Some pesticide chemicals are excreted from plant roots, but the quantities are very small and only the roots in the stream or hydrosoil would add chemicals to the water. How much chemical enters the stream in this way has not been studied.

Movement To Streams From The Forest Floor And Soil

Two competing reactions, leaching or infiltration and surface runoff, are the ways by which chemicals are moved from spray areas to streams. Factors favoring infiltration will decrease the amount of surface runoff and with it the overland flow of introduced chemicals. The amount of chemical actually entering a stream due to surface runoff will depend on:

1. Distance from treated area to the nearest stream,
2. Infiltration properties of the soil or surface organic layer,
3. Rate of surface flow, and
4. Adsorptive characteristics of surface materials.

Conditions that retard the rate of surface runoff will minimize the immediate level of stream contamination. The long-term stream load of pesticide will be reduced as well, since a longer residence time in the soil provides greater opportunity for adsorption and degradation.

Runoff from agricultural lands and discharge from manufacturing plants are the principal sources of water pollution by pesticides (Nicholson 1967). Barnett and others (1967) maximized the probability of runoff by applying artificial rain (2.5 in/hr) to recently tilled agricultural land and found 38 percent of the 2,4-D isooctyl ester in washoff (sediment plus water), but only 5 percent of the 2,4-D amine salt. In another study, only small amounts of 2,4,5-T and picloram moved from compacted sod or recently plowed fallow clay loam soil following artificial rainfall of 0.5 inch in 1 hour (Trichell and others 1968). Movement of contaminated water over untreated soils significantly reduced the concentration of herbicide in the runoff (table XI.4).

Table XI.4.—Effect of slope, rate of application, and movement over untreated sod on the concentration of picloram in runoff water[1] [2]

Rate (lb/ac)	Slope (percent)	Portion of plot treated	Picloram in runoff water[3]	Applied picloram runoff
	Percent		ppm	Percent
2	8	Upper half	2.1	1.6
1	8	Entire	3.8	5.5
2	3	Upper half	1.3	0.9
1	3	Entire	2.0	2.8

[1] Data from Trichell, and others 1968.

[2] Picloram applied as potassium salt in water .88 lbs/ac (400 g/ac).

[3] Simulated rainfall was 0.5 in/hr, 24 hours after herbicide application.

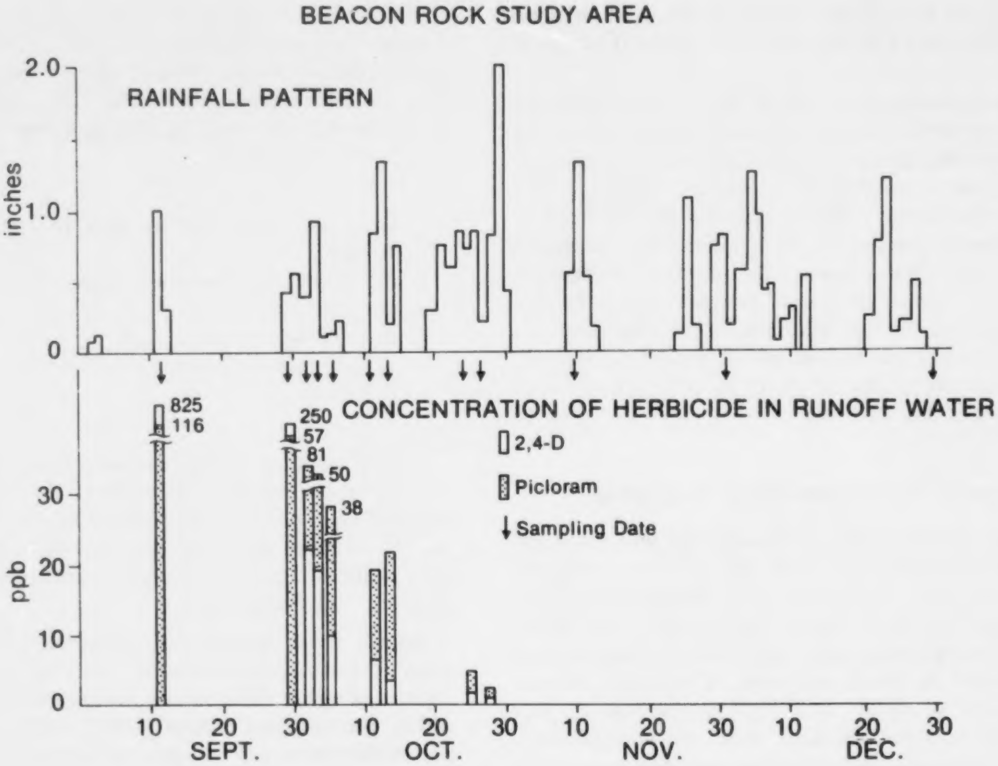


Figure XI.7.—Precipitation and herbicide runoff patterns at the Beacon Rock Study area. A total of 6 and 1.5 lbs/ac of 2,4-D and picloram, respectively, was applied in two treatments (July and August 1967). Herbicide residues were measured in ponded drainage water from the treated area (Norris 1969).

In areas where runoff is likely to occur, pesticide washoff will be greatest during the first storms after the pesticide is applied. The greatest potential for pesticide movement exists when significant amounts of precipitation occur shortly after application. On a powerline right-of-way in southwestern Washington, the highest concentrations of the herbicides 2,4-D and picloram in runoff water were associated with the first significant storm following the herbicides' application (fig. XI.7). The concentrations of herbicides declined with time despite subsequent storms of even greater intensity (Norris 1969). Mobilization of chemicals in transitory stream channels by the expanding stream system described by Hewlett and Hibbert (1967) is believed to account for the immediate flush of chemical observed with the first significant storms. Norris and others (1976a, 1976b) found the total discharge of picloram and trichlopyr from two watersheds was approximately equal to the amount of chemical applied to an ephemeral stream channel.

There is ample evidence to show that phenoxy and amitrole herbicides are not lost in runoff during intense fall precipitation from lands treated with herbicides in the spring in western Oregon (Norris 1968). Favorable conditions and ample time for degradation of the herbicides under these circumstances reduce the chance that they will be mobilized in ephemeral stream channels.

In order to determine to what extent trichlorfon might move with surface runoff, Chemagro (1971) sprayed this insecticide on sloping plots of three soil types at 20 pounds active ingredient/acre. Simulated rainfall was then applied once weekly for 5 weeks. After the 5-week period, total residue in runoff water from a silt loam soil was 2.86 percent of the total applied. Losses from a sandy loam were 0.65 percent, and from a high organic silt loam, 0.35 percent.

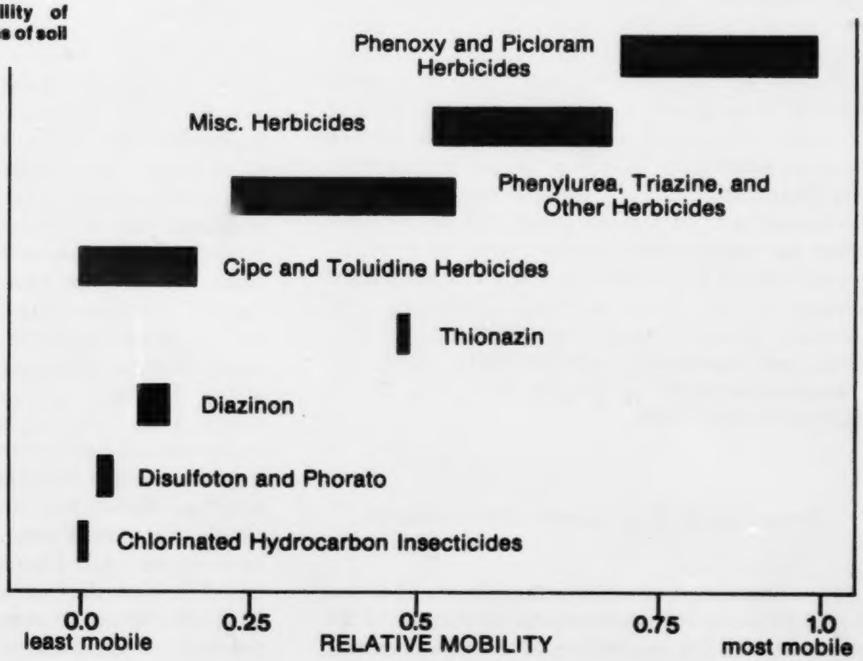
Pesticides leach into the soil profile and subsequently are transported to streams by subsurface drainage; this is another possible route to stream contamination. Leaching, however, is a relatively slow process in highly organic forest soils; only small amounts of chemical move through short distances. Harris (1967, 1969) has determined the relative mobility of pesticides in soil columns leached with water (fig.XI.8). Herbicides in general are more mobile in soil than pesticides, but this mobility is only relative. Even the herbicides move only short distances in the soil under normal conditions (Scifres and others 1969, Wiese and Davis 1964).

Orthene is not tightly bound by soil particles and is, therefore, susceptible to leaching. However, it does not persist long enough to allow any significant movement, either by leaching or surface runoff (Chevron 1973). This compound also degrades rapidly in water. In the laboratory, Orthene showed a half-life in water of 46 days, but, in the field, degradation is accelerated by breakdown in aquatic vegetation and soil microorganisms in bottom mud; measurable residues were gone in 1 to 9 days (Chevron 1973, 1975; Devine 1975).

Boschetti (1966) reported carbaryl residues of 1 to 3 parts per billion (ppb) in streams in or near areas treated for gypsy moth control in the Northeast. In a later study (Devine 1971), carbaryl residue in ponds and streams ranged from nondetectable to 50 ppb during an 8-day period following spraying. Residues in pond mud ranged from nondetectable to 620 ppb.

DDT is very low in water solubility (1.2 μg/l) and is extremely resistant to movement in soil (Bowman and others 1960, Guenzi and Beard 1967, Reikerk and Gessel 1968). Any appreciable movement of DDT through soils by leaching must, therefore, be the result of movement of colloidal particles of the free or adsorbed pesticide. The likelihood of large amounts of the chemical entering the aquatic system seems remote when movement of chemicals by leaching can be measured in inches and the distance between spray units and streams may be hundreds of feet.

Figure XI.8.—Relative mobility of pesticides leached in columns of soil (Harris 1967, 1969).



Summary Of Pesticide Entry Into The Aquatic Environment

To summarize, most chemicals enter the aquatic environment through either direct application or drift of spray materials to the water surface. The forest manager has considerable control over these. Research has demonstrated that direct application of spray materials to water surfaces can be minimized by excluding streams from treatment areas. Careful selection of spray equipment, chemical formulations, and conditions of application will minimize the potential for drift.

Mobilization of residues in ephemeral stream channels during the first significant storms following chemical application is the second most important source of chemical residues in forest streams.

Pesticide residues moving overland with surface runoff during intense precipitation is the third most important way by which chemicals may enter the aquatic system. The phenoxy herbicides, amitrole, and the carbamate and pyrethrum insecticides degrade rapidly so they are available for overland transport to streams for only short periods. Picloram may persist for more than one season, but its tendency to leach into the soil profile reduces its chances of moving by surface runoff into streams. DDT and similar compounds are resistant to degradation and leaching, therefore, they are exposed to overland transport for extended periods of time. However, the chlorinated hydrocarbon insecticides are no longer selected for use in forestry when alternate chemicals are available. Overland flow of water on forested watersheds is relatively uncommon, and pollution of streams from this source will be limited to areas where rates of infiltration are considerably less than normal rates of precipitation. The stream contamination that does occur will be reduced when the contaminated water moves over the untreated buffer strips. Leaching is not a significant process in the entry of forest chemicals into streams. Specific Controls are listed under "Aerial Drift and Application of Chemicals," and "All Resource Impacts" in Section B of Chapter II: Control Opportunities.

Behavior In The Aquatic Environment

How an aquatic organism responds to a chemical will depend on the duration and magnitude of the exposure and the interaction of the organism with other stresses in its environment. How a chemical behaves in the aquatic environment will determine both duration and magnitude of the exposure.

Chemicals may be lost from the aquatic environment through volatilization; adsorption in stream sediments; absorption by aquatic biota; degradation by chemical, biological, or photochemical means; or dilution with downstream movement (fig. XI.2).

Volatilization

The amount of pesticide lost from water by volatilization varies with both the properties of the chemical and the environmental conditions. The chlorinated hydrocarbon insecticides (like DDT) are of very low solubility in water and tend to collect at water surfaces in films where they may be subject to co-distillation. Water suspensions containing 5 $\mu g/l$ DDT have been reported to lose 30 percent of the insecticide in 20 hours at 79° F (26° C) (Bowman and others 1964). Fuel oil carriers may concentrate oil soluble pesticides at water surfaces (Cope 1966).

Adsorption

In turbulent streams chemicals will be quickly dispersed throughout the water allowing maximum interaction with various adsorbing surfaces (Cope and Park 1957). Reductions in pesticide concentrations in water by adsorption depend on the rate, extent, and strength of adsorption, and the mixing characteristics of the stream (which will govern the opportunity for interaction within the stream bottom). Researchers have given these factors only limited attention. Clay and fine silt are effective in adsorbing and reducing the activity of DDT and other chlorinated hydrocarbon insecticides in river water (Ferguson and others 1966, Fredeen and others 1953). Bottom sediments from bodies of water treated with various phenoxy herbicides frequently contain residues which may indicate adsorption (Bailey and others 1970, Smith and Ison 1967). Aly and Faust (1965) reported that the amounts of 2,4-D adsorbed on suspended clays in water were small. Considerable research is needed to clarify the importance of adsorption in reducing pesticide concentrations in water.

Degradation

There are conflicting reports on the persistence of pesticides in streams. In one study, 2,4-D esters were hydrolyzed to free acid in 9 days in lake water, but 2,4-D acid persisted up to 120 days (Aly and Faust 1964). In another study, only 40 percent degradation of 2,4-D in water was observed in 6 months, during which excellent conditions for biological activity were present (Schwartz 1967). A considerable decrease in degradation of 2,4-D was observed in bacterially active natural river waters that had reduced levels of dissolved oxygen (fig XI.9).

Robson (1968) reported that the persistence of 2,4-D in fresh water was decreased from 9 weeks to 1 week when small quantities of soil previously treated with phenoxy herbicides were added. Rapid degradation of 2,4-D occurred in water samples collected from areas with a history of repeated 2,4-D applications (Goerlitz and Lamar 1967). Many surface waters may lack suitable conditions for biological degradation of herbicides or they may not contain populations of microbes adapted to use of the phenoxy herbicides as substrates (Hemmet and Faust 1969).

Degradation of certain chemicals is pH dependent. Amitrole resists degradation in activated sludge cultures, distilled water, or sewage held at room temperatures for various periods of time (Ludzak and Mandia 1967). Carbaryl rapidly degrades in sea water, but it will persist for longer periods in the more acid conditions found in forest streams (Aly and El-Dib 1971, Karinen and others 1967). The rapid hydrolysis of malathion in water is also pH dependent (Guerrant and others 1970), 50 percent decomposition occurred in 26 days at pH 6.0 and in 2.5 hours at pH 10.0.

In studies conducted as a part of gypsy moth suppression in the Northeast, carbaryl persistence in the aquatic environment was found to be brief. Romine and Bussian (1971) suggest that an initial level of 1 mg/l will be completely gone in 1 to 2 days. In an earlier study, water residues of 30 μg/l dropped to 1-5 μg/l in 1 day (USDA 1964).

Carbaryl, the phenoxy herbicides, amitrole, and picloram are all susceptible to photodegradation (Crosby and Li 1969, Karinen and others 1967). The importance of this reaction in the natural environment is questionable, however, because most streams are shaded and there is limited penetration of the water by ultraviolet radiation.

Downstream Movement

Downstream movement of chemicals and the resulting dilution due to natural stream mixing and the addition of uncontaminated water from side streams is one of the most important mechanisms by which the concentration of pesticides in streams is reduced near treatment areas. Although the hazard of exposure is not eliminated until the residues are completely degraded to nontoxic compounds, dilution as the result of downstream movement can reduce the concentrations of pesticides in streams to levels that do not represent a hazard to nontarget organisms. DDT residues were carried downstream in well defined blocks and did not persist for long periods at sampling stations located

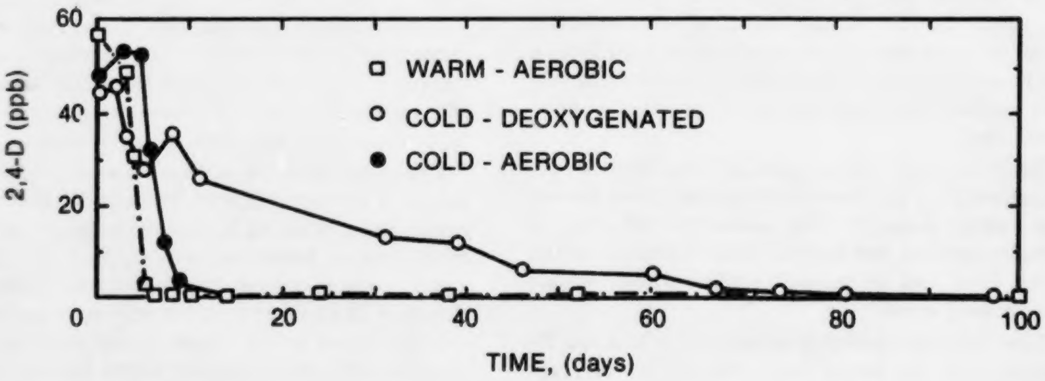


Figure XI.9.—The degradation of 2,4-D in a bacterially active water culture (DeMarco and others 1967).

along an 85-mile stretch of the Yellowstone River following spray operations in Montana (Cope 1961). Marked reductions in concentrations of amitrole and the phenoxy herbicides were observed in water due to downstream movement (Marston and others 1968, Norris and others 1966).

CHEMICAL BEHAVIOR OF FERTILIZERS

Initial Distribution In Air, Vegetation, And Forest Floor

Many concepts concerning the initial distribution of pesticides apply also to fertilizers, but there are some important exceptions. The rate at which nitrogen fertilizer is applied varies with site and timber type but is usually 150 or 200 pounds of urea nitrogen/acre. Phosphorus is applied at rates between 80 and 100 pounds P_2O_5/acre in the southeast. In contrast with pesticides, where significant quantities may remain in the atmosphere, essentially all of the fertilizer applied reaches the intended target. However, because of the higher rates of application, it is necessary to make at least two flights over the unit and a uniform rate of application over an entire unit is difficult to obtain (Strand 1970).

The introduction of large, specially coated urea granules (forest grade) has eliminated the drift problems that were experienced when standard agricultural urea was used. Drift problems still exist, however, when standard agricultural urea (45% N) is used, or when experimental liquid formulations of nitrogen are substituted for the forest granules. Should liquid fertilizer formulations come into commercial use, their initial distribution in the environment will be subject to the same factors controlling distribution of aerially applied pesticides.

Because very little granular fertilizer is intercepted by a dry forest canopy, the forest floor is the major receptor. The initial distribution of aerially applied fertilizers is thus restricted to the forest floor and to exposed surface waters within the treated areas.

Urea fertilizer is highly water soluble and readily moved into the forest floor and soil by any appreciable amount of precipitation. Under normal conditions, urea is rapidly hydrolyzed (4-7 days) to the ammonium ion by the enzyme urease. When moisture is limited, however, urea granules may be slowly hydrolyzed on the forest floor, resulting in a marked increase in surface pH and a loss of ammonia nitrogen by volatilization. In a laboratory study, Watkins and others (1972) measured losses of ammonia nitrogen ranging from 6 percent to 46 percent of the urea nitrogen applied to forest floor and soil depending on the nature of the surface, surface pH, and rate of airflow across the surface. Although some applied nitrogen is undoubtedly lost by volatilization in the field, it is generally conceded that such losses are small. Time of application is important, and forest fertilization projects are usually conducted during the spring or fall months to take advantage of precipitation. Urea nitrogen is quickly distributed throughout the living complex, becomes a part of the nutrient budget, and is cycled within the ecosystem.

$$CO(NH_2)_2\ [\text{solid}] \xrightarrow{H_2O} CO(NH_2)_2\ [\text{solution}]$$

$$CO\ (NH_2)_2 + 2H_2O \xrightarrow{\text{urease}} (NH_4)_2CO_3$$

$$(NH_4)_2CO_3 \xrightarrow{H_2O,\ CO_2} 2\ NH_4HCO_3$$

Entry Of Fertilizers Into The Aquatic Environment

Fertilizer chemicals may enter the aquatic environment by one of several routes. Direct application of chemicals to exposed surface water is the most important way. This can be minimized by carefully marking and avoiding larger streams during applications, but it is usually impractical to avoid small headwater streams, which frequently are intermittent and difficult to see from the air. Exposed surface water may absorb ammonia nitrogen that has volatized from the forest floor into the air. It is doubtful, however, that this source adds significant amounts to the streams.

Overland flow, or surface runoff, is a major source of nutrients in streams draining nonforested areas, but it is not an important route for fertilizers from treated forest watersheds to enter streams since surface runoff rarely occurs. Subsurface drainage is another possible way soluble forms of nitrogen enter into streams. Forest soils are excellent filters for most plant nutrients because of their high exchange capacities and dense root systems which can absorb and recycle nutrients (Moore 1970). However, measurable levels of ammonium-, nitrate-, urea-, and organic-nitrogen have been found in several streams that were monitored for water quality in western Oregon and Washington.

There is an enormous amount of literature concerning the effects of farm fertilization on water quality, but only a few papers concerning the effects of forest fertilization. Soileau's (1969) extensive bibliography (701 entries) on effects of fertilizers on water quality contains no references on effects of forest fertilization.

Several forest fertilization projects have been monitored recently and examples of the data obtained are presented in appendix XI.B. Data from one study conducted in the Pacific Northwest are discussed below to illustrate the magnitude and pattern of nutrient loss to streams. Measures that may be used to minimize the potential for stream contamination are also indicated.

Moore (1971) measured the amounts and forms of nitrogen entering streams during and following aerial application of 200 lbs/ac of nitrogen (as urea) to an experimental watershed in southwestern Oregon in March 1970 (fig XI.10). Data obtained during the first 15 weeks after application are summarized in table XI.5. Urea concentrations increased slowly and reached a maximum of 1.39 mg/l urea-N 48 hours after application started. Ammonium-N increased slightly above pretreatment level, but never reached 0.10 mg/l. Nitrate-N began to increase slowly the second day, reached 0.168 mg/l in 72 hours, and was 0.140 mg/l at the end of 2 weeks. Nitrite-N was not detected and wouldn't be expected to occur in well aerated streams.

All urea losses of applied nitrogen occurred during the first 3 weeks. Losses in the form of ammonium-N, even though small, continued for 6 weeks. During the first 9 weeks after application, net loss of applied nitrogen amounted to only 1.81 kilograms from watershed 2 (table XI.6).

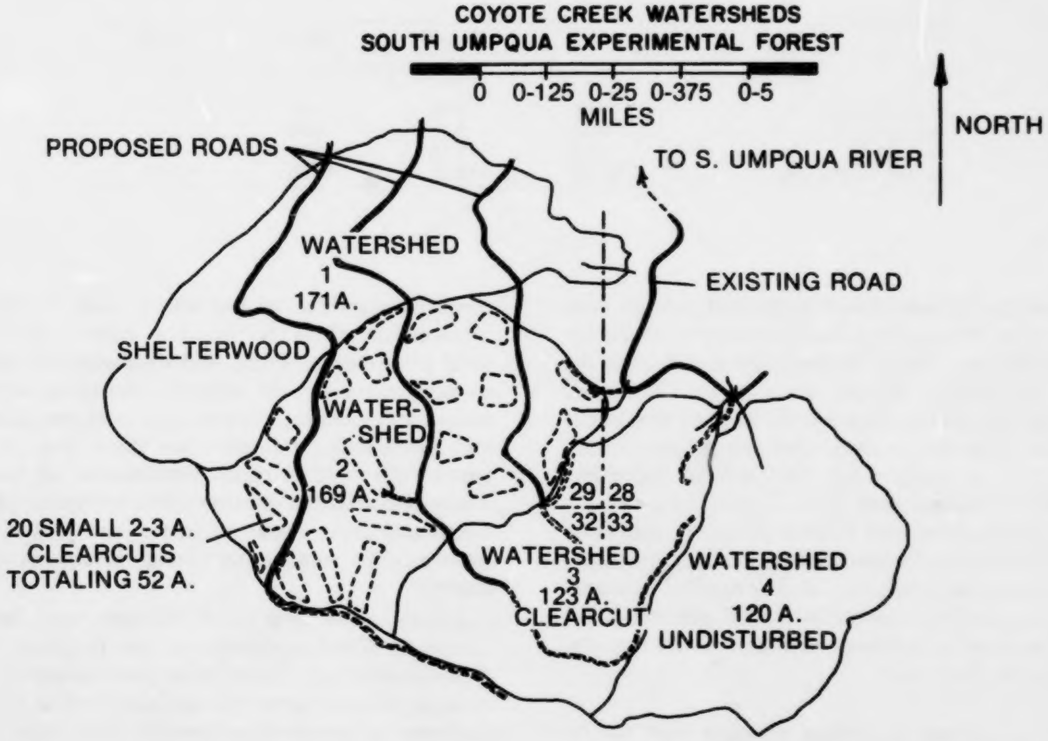


Figure XI.10.—Coyote Creek watersheds, South Umpqua Experimental Forest, Umpqua National Forest, Oreg. (Moore 1971).

Table XI.5.—Concentration of fertilizer nitrogen in selected water samples collected at watershed 2, South Umpqua Experimental Forest, following application of 200 pounds urea-N/ac (Moore 1971)

Date	Time	Urea-N	NH_3N[1]	NO_3-N	Total
			mg/l		
3/25	0800	.007	.001	.002	.010
3/26	0815	.437	.016	.040	.493
	1230	.237	.012	.069	.318
	2025	.171	.034	.067	.272
3/27	0805	1.389	.048	.107	1.544
	1640	.606	.036	.150	.792
	2005	.488	.029	.168	.685
3/28	0805	.075	.036	.117	.228
4/1	---	.007	.016	.091	.185
4/8	---	.028	.015	.140	.183
4/15	---	0	.010	.030	.040
4/22	---	0	.010	.021	.031
5/6	—	0	.013	.022	.035
5/27	---	---	0	.004	.004
6/17	---	---	0	.002	.002
7/8	---	---	0	.006	.006

[1] Includes both ionized (NH_4^+) and un-ionized (NH_3) ammonia-nitrogen

Table XI.6.—Nitrogen lost from treated watershed 2 and untreated watershed 4, South Umpqua Experimental Forest, during the first 9 weeks after application of 224 kilograms urea-N/ha (Moore 1971)

Unit	Urea-N	NH_3-N	NO_3-N	Total
		Kilograms N		
Watershed 2	0.65	0.28	1.01	1.94
Watershed 4	0.02	0.06	0.05	0.13
Net loss	0.63	0.22	0.96	1.81
Percent of total loss	34.75	12.25	53.00	100.00

Low streamflow caused by limited precipitation throughout the summer and fall months resulted in essentially no loss of applied nitrogen during the next 24 weeks. Storm activity in November brought the soil moisture level back to maximum storage capacity. In December the nitrate-N concentration in samples for the fertilized watershed reached a second peak of 0.177 mg/l (fig. XI.11). Both streamflow and nitrate-N levels remained high throughout December and January, resulting in the loss of an additional 23.8 kg applied nitrogen. This second peak accounted for 92 percent of the total amount of fertilizer nitrogen which was lost during the first year.

Total net loss of applied nitrogen from the fertilized watershed (68 ha) during the first year amounted to 25.85 kg, or 0.38 kg of nitrogen/ha (table XI.7). Over the same period the total amount of soluble inorganic nitrogen lost from the control watershed (49 ha) was 2.15 kg, or 0.04 kg nitrogen/ha. Data for soluble organic nitrogen, total phosphorus, silica, and exchangeable cation content of the stream samples, including sodium, potassium, calcium, magnesium, iron, manganese, and aluminum, indicate that there was no apparent effect of nitrogen fertilization on loss of native soil nitrogen or other plant nutrients. Movement may have occurred in the soil profile, but there was no measurable change in stream water quality.

Initial losses of applied nitrogen were largely caused by direct application of urea fertilizer to the drainage channel. These losses were measured first as an increase in urea-nitrogen and then as a small increase in ammonium-nitrogen, the latter as a result of hydrolysis of urea applied to open water. The nitrate-nitrogen entering the stream shortly after application was probably leached from the soil immediately adjacent to the stream channel.

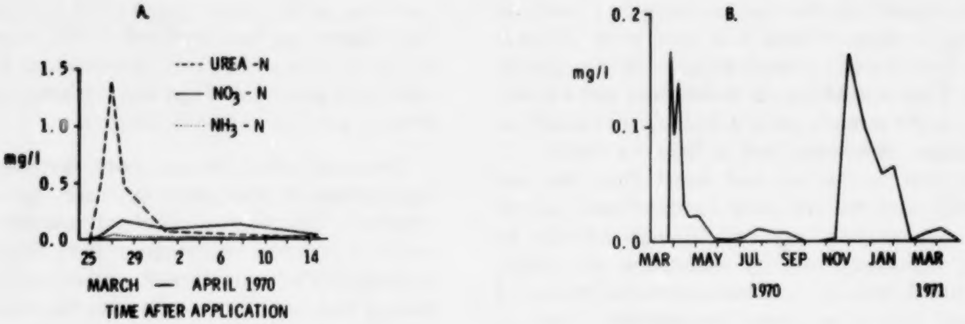


Figure XI.11.—Fertilization of a 68-ha watershed with 224 kg urea-nitrogen/ha in March 1970. A. Immediate effect on water quality; B. Effect on nitrate-nitrogen concentration in streamflow for 1 year following fertilization (Fredriksen and others 1975).

During the first 9 weeks after application, approximately half of the applied nitrogen was lost through direct application and half entered the stream as nitrate-nitrogen. However, all of the applied nitrogen lost during this 9-week period amounted to only 7 percent of the total loss that occurred over the first year.

High streamflow coupled with the second peak in nitrate-nitrogen levels during the winter storm period accounted for 92 percent of the total loss. In February and March 1971, streamflow remained high, but most of the mobile nitrogen had already been lost, and nitrate-nitrogen concentrations had returned to near normal.

Similar data have been obtained in each of the monitoring studies that have been conducted in the Douglas-fir region and elsewhere. The length of the monitoring period has varied from a few weeks following treatment to 6 or 7 months, and in a few studies monitoring continued for at least a full year. Sampling usually continued until the forms of nitrogen being measured decreased to near pre-treatment levels. Increases in the concentration of urea-N are almost entirely caused by direct application to surface waters, and the peak concentration reached is directly proportional to the amount of open surface water in the treated unit. Peak concentrations above 5.0 mg/l are in every case associated with projects where no buffer strips were left along the main streams; or where fertilizer application was carried out early in the spring, when the drainage system was greatly expanded by spring runoff of snowmelt. Even when buffer strips of 30 to 90 m are left along main streams and tributaries, some direct application to water surfaces still will occur because of a relatively dense network of small feeder tributaries that are only a foot or two wide and cannot be identified from the air.

Peak concentrations of urea-N do not persist for more than a few hours. Concentrations characteristically reach a peak each day that fertilizer is being applied and then drop rapidly back toward pre-treatment levels. Within 3 to 5 days after application is completed, levels of urea-N in the stream have returned to pre-treatment concentrations.

Table XI.7.—Nitrogen lost from treated watershed 2 and untreated watershed 4, South Umpqua Experimental Forest, during the first year after application of 224 kilograms urea-N/ha (Moore 1971)

Unit	Urea-N	NH_3-N	NO_3-N	Total
	kilograms N			
Watershed 2	0.65	0.28	27.09	28.03
Watershed 4	0.02	0.06	2.07	2.15
Net loss	0.63	0.22	25.02	25.88
Percent of total loss	2.44	0.86	96.70	100.00

Ammonium-N levels also increase as a result of direct application of urea-N to open water. Urea is readily hydrolyzed to ammonium-N in the aquatic system. Urea applied to the forest floor and soil will not reach the stream since it hydrolyzes rapidly to ammonium carbonate and is held on cation exchange sites in the soil and forest floor like any other salt. Concentrations of ammonium-N in the stream are rapidly reduced through uptake by aquatic organisms and by adsorption on stream sediments. Levels in the streams sampled exceeded 1.00 mg/l only when direct application of urea to the stream was noted. Peak concentrations are normally 0.10 mg/l or less and do not persist for more than a few hours, but levels of ammonium-N remain slightly above pre-treatment level for up to 3 and 4 weeks.

The peak concentration of nitrate-N in stream samples usually occurs from 2 to 4 days after fertilization. Magnitude of the peak concentration depends on whether buffer strips are left along the main stream channels, the width of the waterside area, and the density of small feeder and tributary streams in the drainage system of the fertilized area. Peak concentrations of nitrate-N are generally below 1.0 mg/l, but higher levels have been measured in a few studies. Concentrations usually decrease rapidly after the peak is reached, but remain above pre-treatment level for 6 to 8 weeks. In monitoring studies where sampling has continued through the first winter following fertilization, additional peaks in the concentration of nitrate-N have been measured. These peaks usually coincide with the more intense winter storms, and the concentration drops sharply between storms. Maximum concentrations measured are still low and tend to decrease with each successive storm.

Losses of applied nitrogen are usually very small because the maximum concentrations are generally low, and streamflow decreases rapidly with the onset of the growing season. Following spring application, about half of the applied nitrogen entering the stream during the first 30 days is from direct application and is measured as urea-N and ammonium-N; the other half enters as nitrate-N. All subsequent losses of applied nitrogen to the stream enter as nitrate-N. During early fertilization projects, where buffer strips were either inadequate or not used, estimated total loss was between 2 and 3 percent of the applied nitrogen. In later projects, where direct application to the open surface waters has been avoided or minimized by buffer strips along the main streams and tributaries, measured amounts of applied nitrogen entering the stream are less than 0.5 percent.

Increased phosphorous concentrations following application of phosphate fertilizers have not been reported. Phosphorus added to forest soils is readily utilized by forest organisms or is rapidly converted to nonsoluble forms. Powers and others (1975) have stated that most forest soils have the capacity to tie up, in nonmobile form, many times the quantity of phosphate that foresters are likely to apply. There have been no reports of significant increases in phosphorous concentration in streams following fertilizer application.

Summary Of Fertilizer Entry Into The Aquatic Environment

The most important mechanism of fertilizer entry into the aquatic environment is direct application to open surface waters. Numerous studies (appendix B) have shown that the amount of applied nutrients entering streams has resulted in minimal increases in the instream concentrations of nitrogen and phosphorus. When direct application of fertilizer to streams can be reduced or prevented by use of adequate buffer strips and marking of water courses, the potential impact on stream quality can be minimized.

Transport of mobile forms of nitrogen (nitrate-N) to streams by subsurface drainage from the riparian zone during dormant season storms is the second most important mechanism by which fertilizer nitrogen may enter the aquatic system. Again, the use of adequate buffer strips will reduce the potential impact on water quality. Nitrogen that does enter the stream is rapidly decreased through utilization by biological communities in the stream. Concentrations are further reduced by dilution with downstream movement. Studies conducted to date indicate that forest fertilization will not result in degradation of water quality to the detriment of other resources. With only one exception, none of the studies have recorded nitrogen concentrations that approach the Public Health Service maximum permissible levels for drinking water (Moore 1971, Hornbeck and Pierce 1973, Moore 1975b, Sopper 1975, Norris and Moore 1976, Newton and Norgren 1977).

Behavior In The Aquatic Environment

Forest fertilizers properly applied to an entire watershed undoubtedly will change the nutrient balance among soil, vegetation, animal life, and water in the forest ecosystem, but should pose little or no threat to water quality (Cole and Gessel 1965). Fertilizers applied directly into streams, however, do represent a potential problem, and the total impact of the introduced chemicals will depend on their behavior in the aquatic environment.

When urea nitrogen is introduced into small streams of forested watersheds, either from wildlife activity or through aerial application of fertilizers, it disappears rapidly and only traces can normally be detected in undisturbed ecosystems. Urea is hydrolyzed to ammonium nitrogen by urease enzyme adsorbed on suspended solids and bottom sediments. Ammonium nitrogen may remain in solution or be adsorbed by suspended organic and inorganic colloids and bottom sediments. All forms of nitrogen are diluted by downstream movement caused by natural stream mixing and increased flow volume from side streams and ground water. Dissolved inorganic and organic nitrogen may also be removed by aquatic organisms to such an extent that they are undetectable at a downstream sampling point (Thut and Haydu 1971).

Phosphorus is not considered a mobile element in the soil system. Even those forms of phosphorus that are readily available for plant uptake are not subject to leaching to any significant extent. Phosphate fertilizer applied to a forest watershed would not be expected to enter the stream system except by direct application. Since most headwater streams in relatively undisturbed forest watersheds contain only low concentrations of phosphorus, the small amounts of phosphorus added during a normal fertilization program would be rapidly utilized by the biological community in the stream. Many of the streams in forested areas of the Douglas-fir region are nutrient deficient, and it has been suggested that forest fertilization may have a beneficial effect on forest stream productivity (Thut and Haydu 1971).

The fate of nitrogen applied to cultivated crops has been studied extensively (Allison 1966), but only limited data are available on the nitrogen cycle in temperate forests (Cole and others 1967, Weetman 1961). The output of nitrogen in drainage from actively growing forest stands appears to nearly balance inputs in precipitation (Cooper 1969). Since stream enrichment resulting from forest fertilization is apparently small and of short duration, it can be assumed that any deleterious effects that do occur will not persist. However, the effect of small additions at upstream sites on accumulation of nutrients in downstream impoundments must be considered.

CONCLUSIONS

The amount of a particular chemical that enters a stream will vary depending on many of the factors discussed in this chapter. Each of the components of the forest environment indicated in figure XI.2 can be designated as a compartment in a systems diagram or conceptual model and the various processes responsible for transformation or movement of chemicals within or between compartments identified. With an adequate data base for any given site and a thorough knowledge of the controlling processes, one could then predict the extent of non-point source pollution that would be expected as the result of using a silvicultural practice that includes the application of a pesticide or fertilizer chemical. Although much is known about the behavior of chemicals in the environment, we still lack a precise mathematical model that will meet this objective. Therefore, the major routes of entry of chemicals into forest streams have been identified, and the processes which are involved within each environmental compartment are identified and discussed primarily from a conceptual and qualitative basis. This framework should provide a logical basis for understanding the mechanisms and processes which may result in non-point source contamination of stream water in a qualitative way even though quantitative estimates are not yet possible.

Based on research experience, history of use, consideration of the manner in which most chemical application operations are conducted, and an analysis of the chemical and physical properties which influence the behavior of chemicals in the environment, it is estimated that the following concentrations of various chemicals may be encountered in the aquatic environment near treatment areas.

Herbicides. — A strong background of research experience permits prediction with confidence that concentrations of 2,4-D, picloram, 2,4,5-T, and amitrole exceeding 0.05 mg/l will seldom be encountered in streams adjacent to carefully controlled forest spray operations. Concentrations exceeding 1 mg/l have never been observed and are not expected to occur. The chronic entry of these herbicides into streams for long periods after application does not occur.

Insecticides. — Concentrations of carbamate insecticides exceeding 0.1 mg/l will rarely be found in forest streams. Carbamate and pyrethrum insecticides do not persist in the environment and they offer little opportunity for movement to streams. The organophosphorous insecticide, malathion, is rapidly degraded in soil and water and enters water only by stream channel interception and limited streamside surface runoff. Ultra-low-volume aerial applications will rarely produce more than 0.5 mg/l malathion in streams.

Fertilizers. — There is still only a limited history of field use and research experience concerning the behavior and fate of fertilizer nitrogen introduced into the aquatic environment as a result of forest fertilization. Available data suggest, however, that concentrations of the various forms of nitrogen found in streams adjacent to treated units are well below accepted standards for public water supplies. The impact of these introduced chemicals on various elements of the ecosystem must be investigated.

Direct application to surface waters is the major source of aerially applied forest chemicals in the aquatic environment. Drift is another important pollution source with pesticides, but not with fertilizer. Careful selection of chemicals, carriers, and equipment and control of the manner in which the project is conducted can materially reduce both the direct application and the drift of chemicals to streams. Specific control opportunities were described in Chapter II. Volatilization, adsorption, degradation, and downstream movement of residues will minimize the exposure time of aquatic organisms to chemicals which do enter the aquatic environment.

The forest manager has no control over the inherent toxicity of a selected chemical, but the hazards of chemical use to nontarget organisms can be minimized by limiting their exposure to biologically insignificant doses. Research experience and history of use have established that important forest chemicals offer minimum potential for pollution of the aquatic environment when they are used properly. The key to proper use is an understanding of the ways which chemicals can enter streams and an appreciation of the factors which influence the degree to which these mechanisms operate.

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APPENDIX XI.A
WATER QUALITY DATA — PESTICIDE CHEMICALS

Table XI.A.1.—Cascade Creek Unit, Alsea Basin, western Oregon (Norris 1967)

Sample point 3[1]		Sample point 4		Sample point 5	
Hours after spraying	**2,4,5-T**	**Hours after spraying**	**2,4,5-T**	**Hours after spraying**	**2,4,5-T**
	μg/l		μg/l		μg/l
0.05	0	0.17	1	0.27	lost
0.62	16	1.33	2	1.40	3
1.28	7	2.2	1	2.0	3
2.0	4	3.9	1	3.9	0
4.0	4	5.4	0		
5.2	4				
9.8	4				
24.7	2				
48.2	1				
[2]74.8	1				

[1] Entire watershed feeding the sampled stream was sprayed.

[2] Herbicide was detected for 16 weeks at sample point 3.

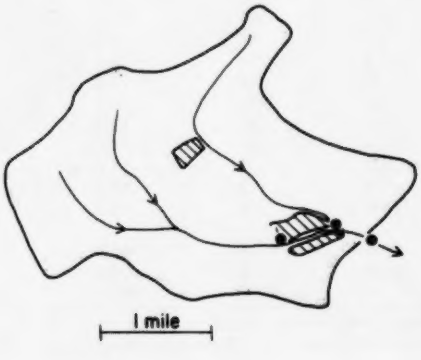


Figure XI.A.1.—Cascade Creek Treatment Unit. (26 ha (2%) of a 1400-ha watershed was treated with 2.24 kg/ha 2,4,5-T. Large streams not included in treatment area.) (Norris 1967).

Table XI.A.2.—Eddyville Unit, Yaquina Basin, western Oregon[1] (Norris 1967)

Sample point 12		Sample point 13		Sample point 14	
Hours after spraying	2,4-D	Hours after spraying	2,4-D	Hours after spraying	2,4-D
	μg/l		μg/l		μg/l
0.83	33	1.33	62	1.38	30
1.83	13	2.3	71	2.3	44
2.8	13	3.3	58	3.3	25
[2]53.5	9	4.3	44	4.3	23
		[2]53.6	25	[2]53.6	11

[1] Rate of application was 2.5 to 3.36 kg/ha.

[2] No further residues detected although sampling continued for 10 months.

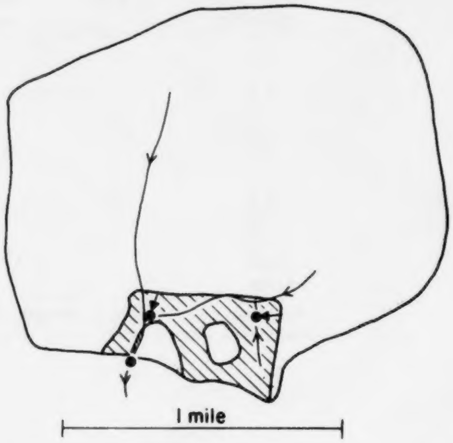


Figure XI.A.2—Eddyville Treatment Unit. (20 ha (10%) of a 287 ha watershed was treated with 2,4-D (LVE) at rates ranging from 2.5 to 3.36 kg/ha. Sampled streams flowed from or through treatment area.) (Norris 1967).

Table XI.A.3.—Concentration of 2,4-D in West Myrtle Creek, Malheur National Forest, eastern Oregon[1] (Norris 1967)

Sample point 1		Sample point 2[2]	
Hours after spraying	2,4-D	Hours after spraying	2,4-D
	μg/l		μg/l
1.7	132	2.0	0
3.7	61	3.9	0
4.7	85	5.0	0
6.0	10	6.2	2
7.0	26	7.2	7
8.0	75	8.2	8
9.0	59	9.2	13
13.9	51	14.1	14
26.9	3	17.0	7
37.9	9	38.0	6
78.0	8	77.8	9
80.8	1	81.0	9
168.0	0	104.8	3
		168.0	1

[1] Rate of application was 2.24 kg/ha.

[2] Sampling point 2 is 1.6 km downstream from point 1.

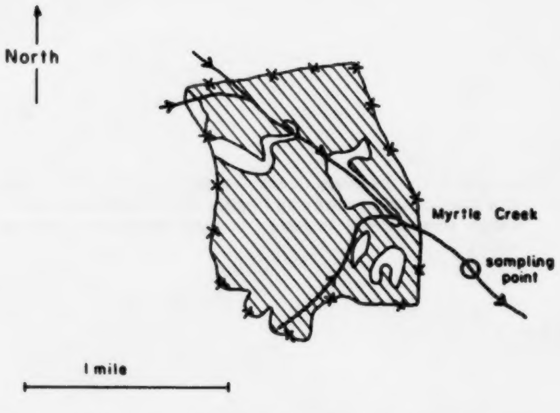


Figure XI.A.3.—West Myrtle Treatment Unit. (240 ha treated in one block. Live streams included in the treatment area.) (Norris 1967).

Table XI.A.4.—Camp Creek Spray Unit, Malheur National Forest, eastern Oregon[1] (Norris 1967)

Hours after spraying	2,4-D
	µg/l
0.1	0
2.0	25
5.4	1
8.8	1
84.5	3
168.0	0

[1] Rate of application was 2.24 kg/ha.

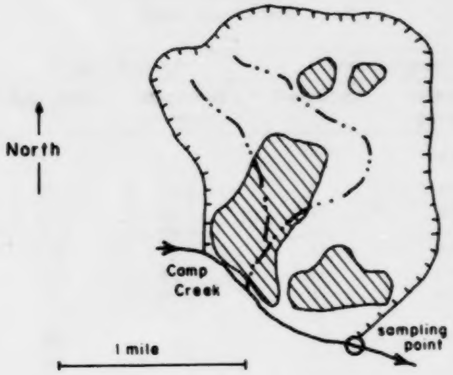


Figure XI.A.4.—Camp Creek Spray Unit. (121 ha treated with 2.24 kg/ha 2,4-D (low volatile esters). Spray boundaries adjacent to, but did not include, live streams.) (Norris 1967).

Table XI.A.5.—Concentration of 2,4-D in streams in Keeney-Clark Meadow eastern Oregon[1] (Norris 1967)

Hours after spraying	2,4-D	Hours after spraying	2,4-D
	µg/l		µg/l
0.7	840	14.3	113
2.5	48	37.8	91
3.1	128	56.4	76
3.6	106	100.1	115
4.1	106	103.6	95
6.1	121	289.9	5
8.1	176	297.0	7
9.6	138		

[1] Rate of application was 2.24 kg/ha.

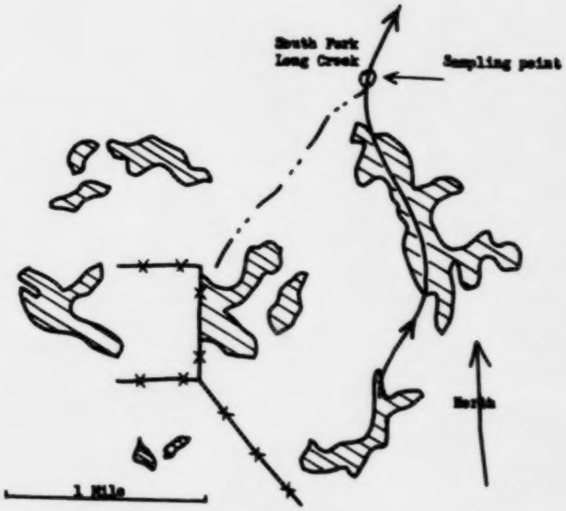


Figure XI.A.5.—Keeney-Clark Meadow Spray Units. (89 ha treated with 2.24 kg/ha 2,4-D. Flat, marshy area with many small live streams and other sites with standing water.) (Norris 1967).

Table XI.A.6.—Concentration of Amitrole-T in Wildcat Creek, Coast Range, western Oregon[1] (Norris and others 1966)

Sample point 2		Sample point 3	
Hours after spraying	Amitrole-T	Hours after spraying	Amitrole-T
	μg/l		μg/l
0.05	1	0.05	0
0.39	30	0.33	0
0.74	35	0.67	9
1.13	37	1.07	90
1.43	17	1.38	110
1.73	16	1.60	40
2.1	19	2.0	35
3.3	21	2.8	24
4.8	12	4.2	14
5.8	8	5.2	7
7.1	5	6.9	5
8.1	4	8.0	5
9.5	3	10.3	3
10.4	2	15.2	2
15.3	1	20.5	25
26.1	7	26.0	8
30.1	4	45.7	3
46.1	2	69.4	0
71.5	0		

[1] Rate of application was 2.24 kg/ha.

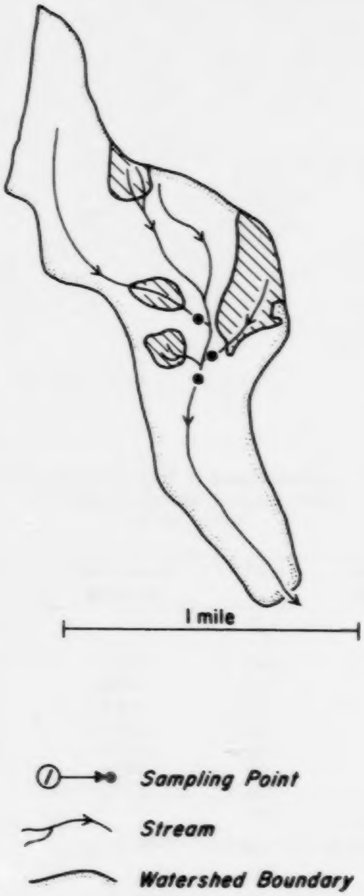


Figure XI.A.6.—Wildcat Creek Spray Unit. (28 ha treated with 2.24 kg/ha amitrole-T. Spray units include live streams.) (Norris and others 1966).

Table XI.A.7.—Concentration of amitrole in stream water, loss or dilution with downstream movement. Amitrole-T applied to 105 ha at 2.24 kg/ha[1] (Norris and others 1967)

Hours after spraying	**Amitrole concentration on sampling point**			
	1	**2**	**3**	**4**
hours	µg/l			
0.1	1	0	0	0
0.5	5	0	0	0
1	7	2	0	0
2	45	42	0	0
3	24	15	0	0
4	8	18	4	0
5	10	5	6	0
6	9	5	6	0
8	3	3	12	0
10	2	2	2	0
12	1	1	2	0
14	1	1	2	0
24	1	2	1	0
35	1	0	1	0
48	0	0	0	0
72	0	0	0	0

[1] Study was conducted in Coast Range of Oregon. Sampling point 1 was located just below boundary of sprayed unit; point 2 was 3.2 km downstream from point 1; point 3 was 0.48 km below point 2; and point 4 was 1.49 km below point 2. No detectable quantity of amitrole was found between 3 and 150 days after treatment.

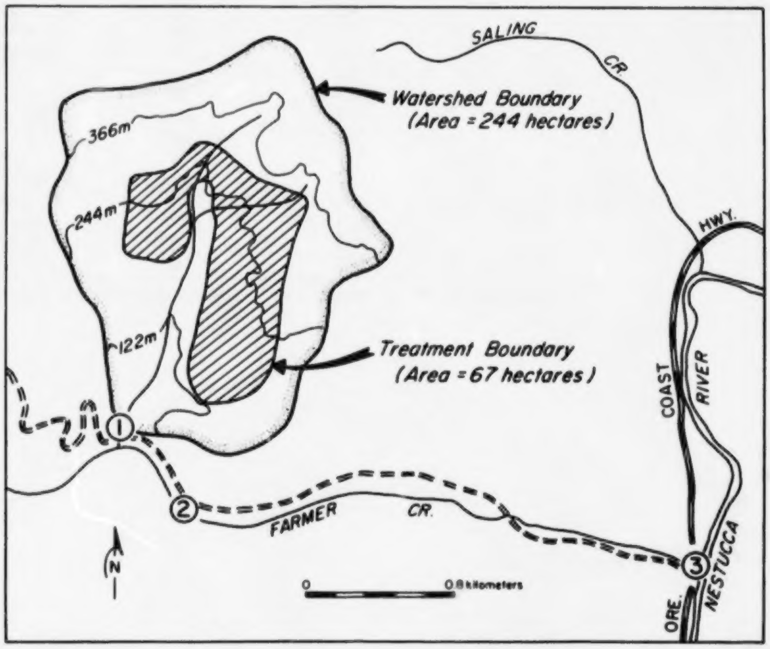

SALING CR.
Watershed Boundary (Area = 244 hectares)
366m
244m
122m
HWY.
Treatment Boundary (Area = 67 hectares)
COAST RIVER
1
2
FARMER CR.
3
NESTUCCA
ORE.
N
0
0.8 kilometers

Figure XI.A.7.—Farmer Creek Treatment Watershed. (67 ha of a 244 ha watershed sprayed by helicopter with 1.12 kg dicamba and 2.24 kg 2,4-D per ha. Sampling point 1 is about 1.3 km from edge of treated unit) (see table XI.A.8) (Norris and Montgomery 1975)

Table XI.A.8.—Concentration of dicamba in Farmer Creek[1] (Norris and Montgomery 1975)

Sampling date	Hours after application	Dicamba	Sampling date	Dicamba
	hours	µg/l		µg/l
6/05/71	(prespray)	0	6/10/71	2
6/07/71	0.3	0	6/11/71	4
	0.6	0	6/13/71	9
	1.0	0	6/16/71	0
	1.2	0	6/18/1	2
	1.7	0	6/21/71	0
	2.1	1	6/30/71	0
	2.5	0	7/08/71	0
	2.7	0	7/09/71	0
	3.3	3	8/11/71	0
	3.8	12	8/20/71	0
	4.3	16	8/25/71	0
	4.8	28	9/01/71	0
	5.2	37	9/02/71	0
	6.2	33	9/07/71	0
	6.8	30	9/29/71	0
	7.8	27	10/19/71	0
	8.8	24	11/17/71	0
	10.2	16	11/29/71	0
	13.1	11	12/22/71	0
	22.8	6	5/18/72	0
6/08/71	30.1	2	6/08/72	0
	37.5	0	6/30/72	0
6/09/71	50.2	0	7/28/72	0

[1] Coastal Oregon; 67 ha treated with 1.12 kg/ha dicamba and 2.24 kg/ha 2,4-D.

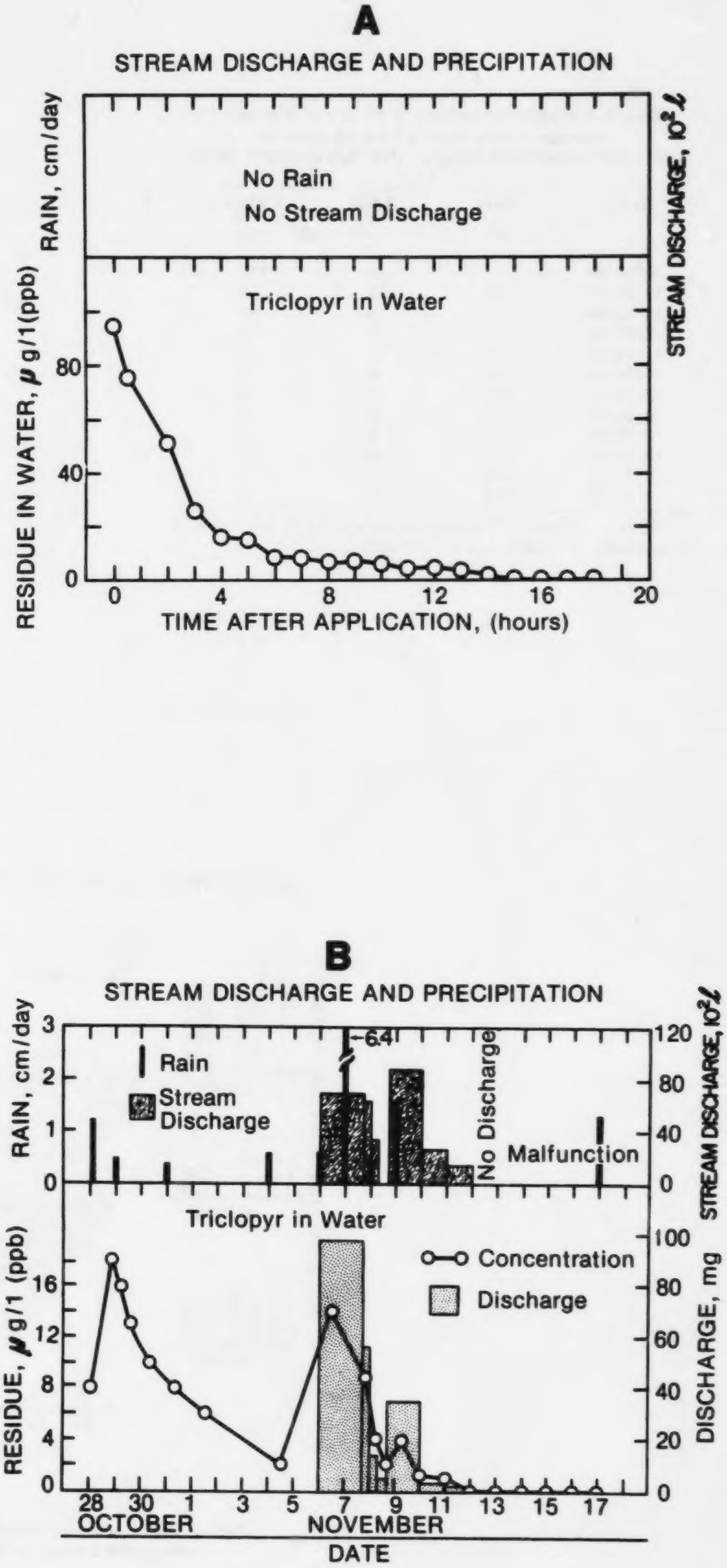


Figure XI.A.8—Precipitation, stream discharge, and concentrations of tryclopyr in stream water following application of 3.36 kg/ha by helicopter to a small watershed in southwest Oregon in May 1974 (Norris and others 1976b).

A. First 20 hours after application.

B. First significant storm activity, channel flushing.

Table XI.A.9.—Concentrations of 2,4-D and picloram in drainage waters from a 7-ha hill-pasture watershed in southwest Oregon[1] (Norris and others 1976a)

Date	Rain	2,4-D	Picloram
	cm.	µg/l	
9/18/69		0	110
10/09/69	7.9	22	43
10/13/69		0	64
10/21/69	3.0	3	39
11/14/69	5.0	0	0
11/24/69	—	0	0
12/01/69	0.1	0	0
12/09/69	2.0	0	0
12/19/69	6.8	0	0
12/24/69	9.9	0	12
1/01/70	4.6	0	1
1/24/70	18.6	0	0

[1] Rate of application—2.3 kg picloram and 4.6 kg 2,4-D in 93.5 l/ha applied as Tordon 212 by helicopter.

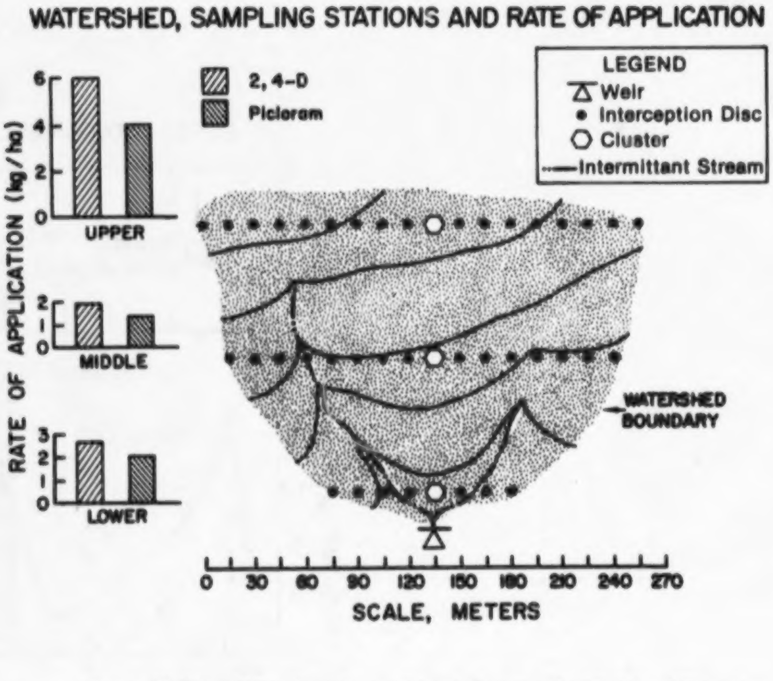


Figure XI.A.9.—Boyer Ranch, southwest Oregon. Small 7-ha hill-pasture spray unit treated with Tordon 212 (Norris and others 1976a).

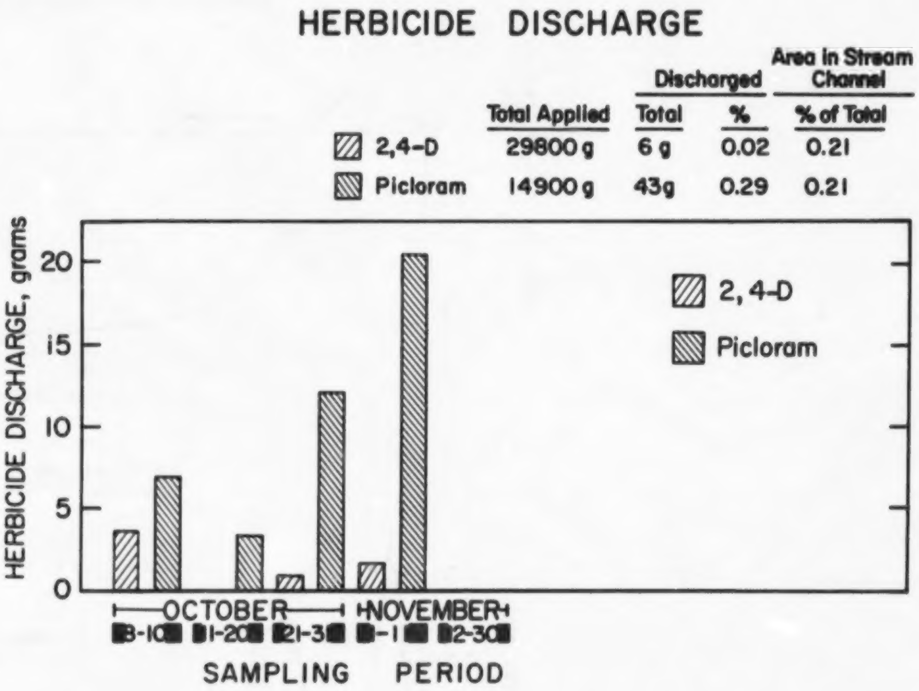
Table XI.A.10.—Total DDT content of stream water flowing from sprayed area — before treatment and for 3 years after treatment[1] (Tarrant and others 1972)

Date	Days after spraying	Total DDT residues in Rattlesnake Creek	
		East Fork	West Fork
		µg/l	
5/24/65	-30	[2]	
6/19/65	- 4	ND	ND
6/23/65	1	.104	.277
7/14/65	21	.031	.022
8/26/65	64	.026	.015
11/17/65	147	.014	ND
6/07/66	349		ND
7/19/66	391	.010	
11/09/66	505	ND	
7/04/67	742	ND	ND
11/07/67	869	.032	.010
7/16/68	1,131		
11/12/68	1,251	.010	

[1] Area sprayed with DDT at rate of 0.84 kg/ha.

[2] Blank = levels of DDT isomers and metabolites less than 0.01 mg/l but greater than 0.002 mg/l.

ND = not detected



HERBICIDE DISCHARGE

	Total Applied	Discharged		Area in Stream Channel
		Total	%	% of Total
▨ 2,4-D	29800 g	6 g	0.02	0.21
▨ Picloram	14900 g	43g	0.29	0.21

Figure XI.A.10.—Discharge of herbicide in streamflow from small 7-ha hill-pasture watershed, Boyer Ranch, southwest Oregon. Treatment was with Tordon 212 at 2.3 kg picloram and 4.6 kg 2,4-D per hectare (Norris and others 1976a).

Note: All of the herbicide discharged with streamflow is accounted for by the quantity applied to the stream channel and adjacent banks. (The question mark for the period December 21 through 31 reflects equipment malfunction resulting in no measure of stream discharge.)

Table XI.A.11.—Concentration of herbicides in water samples, as determined by odor tests[1] (Reigner and others 1968)

Herbicide and time of sample	Pennsylvania streams	New Jersey streams
	µg/l	µg/l
2,4,5-T butory ethanol ester:		
Immediately after spraying	40	40
4 hours later	20	20
Next 9 samples[2]	ND[3]	ND
After first large storm	10	ND
2,4,5-T emulsifiable acid:		
Immediately after spraying	40	20
4 hours later	10	ND
Next 9 samples[2]	ND	ND
After first large storm	20	ND
All downstream samples (both herbicides)	ND	ND

[1] Test panel used procedure approved by American Society for Testing and Materials.

[2] Samples taken daily for first week; twice a week for next 2 weeks.

[3] ND = no detectable odor.

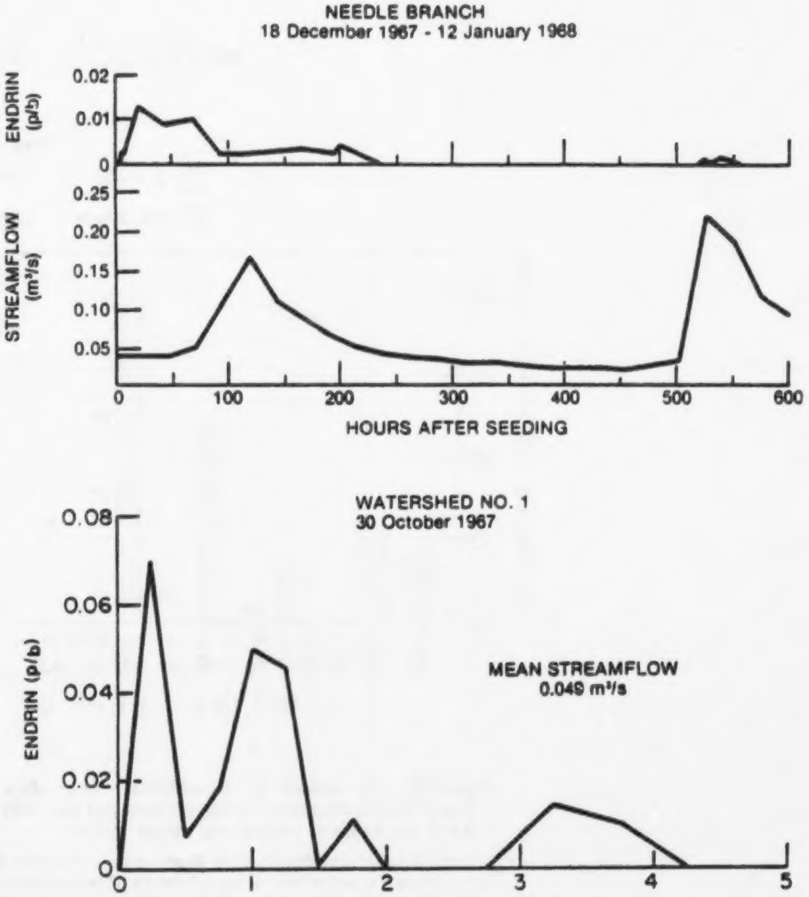


Figure XI.A.11.—Concentration of endrin in streamflow after aerial seeding with endrin-coated Douglas-fir seed. Needle Branch Watershed—seed treated with 1.0% endrin and sown at 0.84 kg/ha; Watershed 1, H.J. Andrews Experimental Forest—seed treated at 0.5% endrin and sown at 0.56 kg/ha (Moore and others 1974).

Table XI.A.12.—Concentrations of 2,4-D and 2,4,5-T herbicide in water samples from Monroe Canyon, San Dimas Experimental Forest, northeast of Glendora, California (Krammes and Willets 1964)[1]

Date	Site			
	Weir	Surface	Well 1	Well 2
	ppm			
May 10/61	0.00	---	---	---
May 22/61	.00	---	---	---
June 5/61	.05	0.09	0.01	0.01
July 24/61	.05	.03	.00	.00
July 31/61	.00	.00	.00	.00
Aug. 28/61	.00	.00	.00	.01
Sept. 25/61	.00	.00	.04	.00
Oct. 30/61	.00	.00	.00	.00
Jan. 29/62	.00	---	---	---
Feb. 26/62	.00	---	---	---
June 20/63	.00	---	---	---

[1] The riparian zone and intermediate slopes of a 354-ha watershed were hand sprayed several times with a mixture of equal parts of 2,4-D and 2,4,5-T in diesel oil. Care was taken to avoid any direct contamination of the stream. A total of 170 l of herbicide was applied on May 10, 1961, but actual rates of application are not known. Maintenance spraying was carried out again in June, 1963, also followed by hand spraying at later dates. Stream contamination was below the safe limit of 1 ppm. No traces of diesel oil were found. Riparian zone vegetation was handsprayed during the week following the May 22, 1961 sampling and just before the June 20, 1963 sampling.

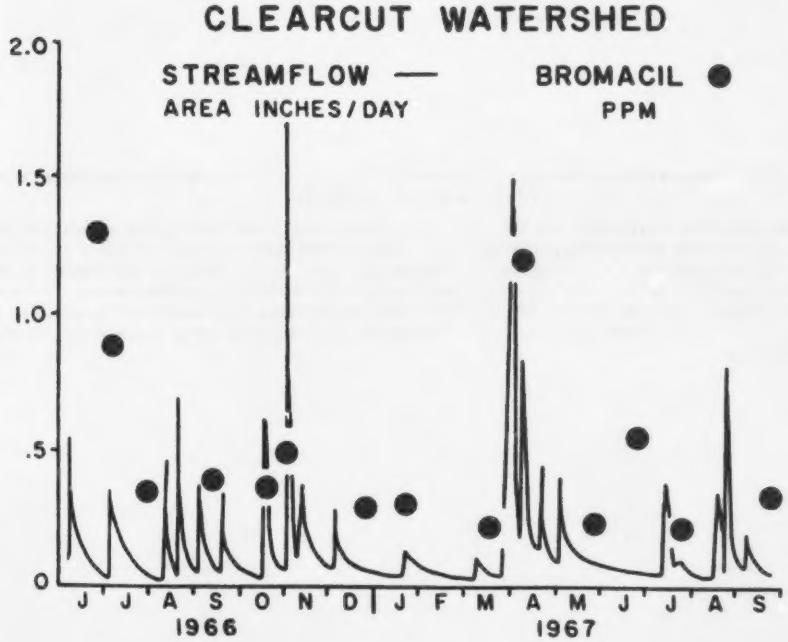


Figure XI.A.12.—Water yield and bromacil release from watershed 2, Hubbard Brook Experimental Forest, West Thornton, New Hampshire (Pierce 1969).

Note: Watershed 2 (15.8 ha) was clearcut of all timber and woody vegetation in late fall and early winter of 1965. In June 1966, bromacil was broadcast sprayed by helicopter at a rate of 28 kg/ha. Persistent sprouts were sprayed with 2,4,5-T in the summer of 1967. About 20 percent of the bromacil left the watershed through the stream in 1½ years. The concentration of 2,4,5-T in the stream was less than 1 mg/l for the entire period following application.

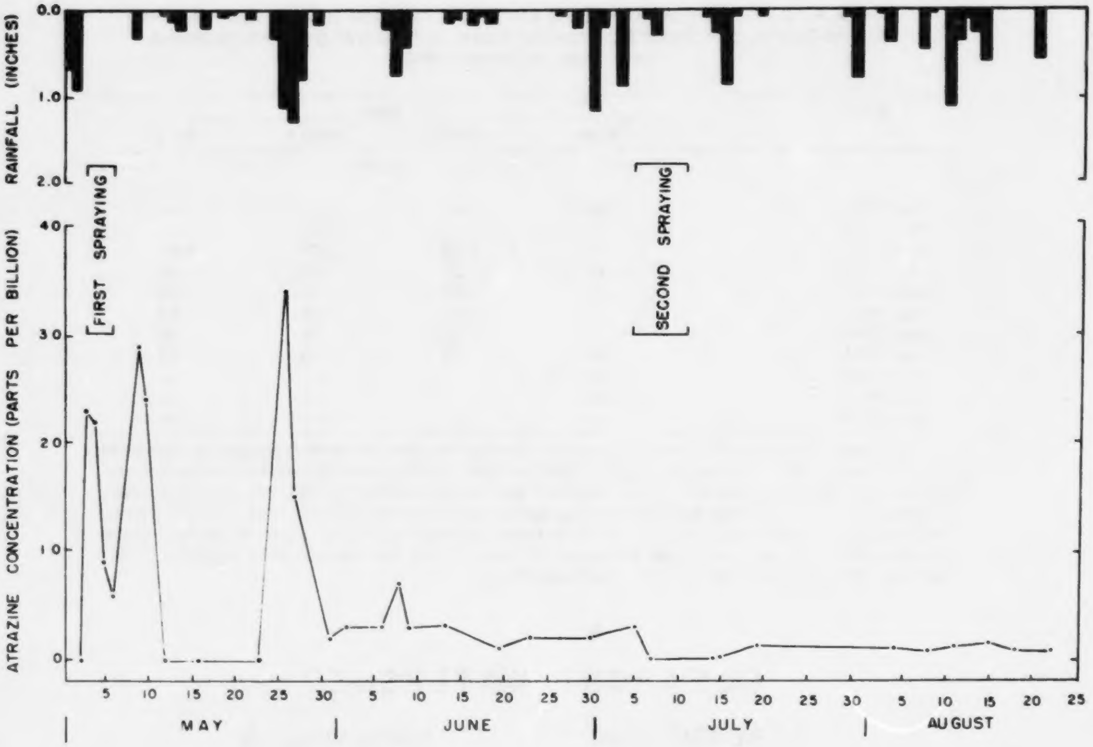


Figure XI.A.13.—Atrazine concentration in streamflow during and for 3½ months after herbicide treatment (Douglas and others 1969).

Note: A 9-ha watershed was treated May 3-6, 1966, with 3.9 kg atrazine and 0.95 l technical paraquat per hectare, including the water course. Surviving vegetation was sprayed again on July 5-11 with a mixture of 3.36 kg 2,4-D (isobutyl esters) and 5 kg atrazine per hectare, but a 3-m buffer strip was left unsprayed on both sides of the stream. Atrazine content in water samples from the stream is graphed above. Paraquat was detected in only 5 of more than 35 samples, and maximum concentration measured was 19 μg/l. After the second spraying, 2,4-D was never detected in the stream and the concentration of atrazine did not increase, even during storms.

APPENDIX XI. B
WATER QUALITY DATA — FERTILIZER CHEMICALS

Table XI.B.1.—Stream water quality following forest fertilization, fall 1975: Hoodsport-Quileene Ranger Districts, Olympic National Forest, Washington (Stephens 1975b)

Treatment: Urea pellets were applied to several thousand acres of second growth Douglas-fir. As a general rule, stream buffer strips of 100 ft (30 m) were left along tributary streams which were flowing greater than 0.5 ft^3/sec (14 l/sec). 300 ft (91 m) wide buffer strips were left along main streams.

Site	Rate of application		Date of application	Treatment area		Range concentrations		
	lb-N/ac	kg-N/ha				Urea-N	NH_3-N	NO_3-N
				ac	ha	mg/l		
McDonald Creek	200	224	Oct.-Nov. 75	316	128			
Pre-treatment						0.01-0.02	0	0.03-0.05
Post-treatment						0.32-0.01	0-0.18	0.03-2.85
Jimmycomelately	200	224	Oct.-Nov. 75	48	20			
Pre-treatment						---	---	---
Post-treatment						0-0.05	0-0.07	0.03-0.13
Gold Creek	200	224	Oct.-Nov. 75	229	93			
Pre-treatment						0	0	0.02-0.05
Post-treatment						0-0.31	0-0.22	0.02-0.18
Elbo Creek	200	224	Oct.-Nov. 75	33	13			
Pre-treatment						0	0	0.01-0.02
Post-treatment						0-0.28	0-0.10	0-0.07
Mile & ½ Creek	200	224	Oct.-Nov. 75	169	68			
Pre-treatment						0-0.02	0	0.06-0.07
Post-treatment						0-0.22	0-0.02	0-0.92
Fulton Creek	200	224	Oct.-Nov.75	592	240			
Pre-treatment						0	0	0.01-0.02
Post-treatment						0-0.13	0-0.10	0.01-0.09
Waketickeh Creek	200	224	Oct.-Nov. 75	1432	580			
Pre-treatment						0-0.01	0	0-0.02
Post-treatment						0-0.84	0-0.55	0-0.40

Table XI.B.2.—Stream water quality following forest fertilization, spring 1975: Hoodsport-Quileene Ranger Districts, Olympic National Forest, Washington (Stephens 1975a)

Treatment: Urea pellets were applied by helicopter to several thousand acres of second growth Douglas-fir. As a general rule, stream buffer strips 200 ft (60 m) wide were left along streams which were flowing greater than 0.5 ft³/sec (14 l/sec).

Site	Rate of application		Date of application	Treatment area		Range concentration
	lb-N/ac	kg-N/ha				NO_3-N
				ac	ha	mg/l
Mile & ½ Creek	200	224	Apr. 75	292	118	
Pre-treatment						0.01-0.03
Post-treatment						0-0.18
Trapper Creek	200	224	Apr. 75	200	81	
Pre-treatment						-0.03
Post-treatment						0.01-0.54
Salmon Creek	200	224	Apr. 75	112	45	
Pre-treatment						0
Post-treatment						0.03-0.65
Eddy Creek	200	224	Apr. 75	240	97	
Pre-treatment						0
Post-treatment						0-0.72
Jackson-Marple	200	224	Apr. 75	460	186	
Pre-treatment						0-0.01
Post-treatment						0-0.50
Turner Creek	200	224	Apr. 75	286	116	
Pre-treatment						0-0.04
Post-treatment						0-0.25

Table XI.B.3.—Stream water quality following a wildfire and fertilization with reseeding for erosion control, 1971: Entiat Experimental Forest, central Washington (Klock 1971; Tiedemann and Klock 1973; and Helvey and others 1974)

Treatment: Following a wildfire in August 1971, three watersheds were monitored for water quality. Fox Creek was used as a control, Burns Creek was fertilized with ammonium sulfate and McCree Creek was fertilized with urea. An unburned watershed, Lake Creek was also monitored as an undisturbed control.

Site	Rate of application		Dates of application	Percent of total applied	Treatment area		Peak concentrations		
	lb-N/ac	kg-N/ha					Urea-N	NO_3-N	NH_4-N
					ac	ha	mg/l		
Fox Creek	Control		no application		1,169	473			
Pre-treatment	1970						[1]0.035	N.D.[2]	N.D.
Post-treatment	1971						N.D.	N.D.	N.D.
McCree Creek	48	54	10/30/70	7.5	1,270	513			
	urea		11/05/70	24.3					
			11/08/70	68.2					
Pre-treatment	1970						N.D.	N.D.	N.D.
Post-treatment	1971						0.616	0.210	<0.02
Burns Creek	51	57	10/30/70	13.6	1,394	564			
	$(NH_4)_2SO_4$		11/09/70	86.4					
Pre-treatment	1970						N.D.	N.D.	N.D.
Post-treatment	1971						0	0.068	0
Lake Creek	Control		no application						
	1972							0.065	

[1] Attributed to wildlife activity

[2] N.D.—Not detected, concentration below detection limit of equipment.

Table XI.B.4.—Stream water quality following forest fertilization, 1970: Mitkof Island, southeast Alaska (Meehan and others 1975)

Treatment: Two areas of cutover land were fertilized in May 1970 by helicopter with urea pellets.

Site	Rate of application		Date of application	Treatment area		Urea-N	NO_3-N	NH_3-N
	lb N/ac	kg N/ha						
				ac	ha	mg/l		
Falls Creek								
Control	---	---	---	---	---			
1970						N.D.	0.23	0.23
1971						N.D.	0.24	0.11
Treated	190	210	May 70	---	---			
1970						N.D.	1.26	1.28
1971						N.D.	1.66	0.11
Three Lakes								
Control	---	---	---	---	---			
1970						N.D.	0.20	0.10
1971						N.D.	0.18	0.12
Treated	190	210	May 70	---	---			
1970						N.D.	2.36	0.14
1971						N.D.	0.30	0.08

N.D. = Not Detected

Table XI.B.5.—Stream water quality following forest fertilization of two small watersheds, 1970 and 1971: Siuslaw River Basin, western Oregon (Burrough and Froehlich 1972)

Treatment: Two watersheds, Nelson Creek and Dollar Creek, were fertilized by helicopter with urea pellets. There were no buffer strips established along watercourses within the treated area. Untreated adjacent watersheds were also monitored as a control.

Site:	Rate of application		Date of application	Treatment area		Peak Concentration		
	lb-N/ac	kg-N/ha				Urea-N	NH_3-N	NO_3-N
				ac	ha	mg/l		
Nelson Creek	200	224	Apr. 70	94	---			
treated						8.6	0.32	7.6
untreated						0.20	0.33	4.3
Dollar Creek	200	224	Apr. 71	85	---			
treated						44.4	0.49	0.13
untreated						<0.02	0.15	0.16

Table XI.B.6.—Stream water quality following fertilization of forested watershed on the Olympic Peninsula, spring 1970: Quileene Ranger District, Olympic National Forest, Washington (Moore 1975b)

Treatment: Two watersheds, Jimmycomelately and Trapper Creek, were fertilized by helicopter with urea. Pelletized or large granule forest grade urea was unavailable so agricultural grade was used. Drift of the fertilizer was noted. The stream was flagged and fertilizer was not applied within 200 ft (60 m) of the stream.

Site:	Rate of application		Date of application	Treatment area		Peak Concentration		
	lb-N/ac	kg-N/ha				Urea-N	NH_4-N	NO_3-N
				ac	ha	mg/l		
Jimmycomelately	200	224	Apr. 70	120	49			
Pre-treatment						0	<0.004	0.002
Post-treatment						0.71	0.04	0.042
Trapper	200	224	Apr. 70	158	64			
Pre-treatment						0.013	<0.004	0.055
Post-treatment						0.71	0.01	0.121

Table XI.B.7.—Stream water quality after fertilization of a small forested watershed on the west slopes of the Cascade Mountains, 1970: Oregon (Malueg and others 1972)

Treatment: A watershed was fertilized by helicopter with urea pellets. No effort was made to prevent the direct application of urea into the water courses.

Site:	Rate of application		Date of application	Treatment area		Concentrations		
	lb-N/ac	kg-N/ha				NH_4-N	NO_2-N	NO_3-N
				ac	ha	mg/l		
Crabtree Creek	200	224	May 70	569	230			
Pre-treatment						<0.01	<0.01	<0.01
Post-treatment						<0.08	<0.01	<0.25

Table XI.B.8.—Stream water quality after fertilization following wildfire in north-central Washington, 1970: Chelan, Washington (Tiedemann 1973)

Treatment: Urea fertilization following wildfire. Falls Creek was fertilized, Camas Creek was not fertilized, and Grade Creek was unburned and unfertilized.

Site:	**Rate of application**		**Date of application**	**Treatment area**		**Peak Concentrations**		
	lb-N/ac	**kg-N/ha**				**Urea-N**	**NH_3-N**	**NO_3-N**
				ac	ha	mg/l		
Falls Creek	70	78	Oct. 70	6,180	2,500			
Pre-treatment						0.330	0.011	0.016
Post-treatment						0.029	0.011	0.310
Camas Creek	---	---	---	1,680	680	0.006	0.001	0.042
Grade Creek	---	---	---	6,920	2,800	[1]0.450	0.011	0.016

[1] Attributed to animal activity.

Table XI.B.9.—Stream water quality following forest fertilization, spring 1976: Quileene Ranger District, Olympic National Forest, Wash. (Stephens 1976)

Treatment: Urea pellets were applied to 800 ac of second-growth Douglas-fir. As a general rule, stream buffer strips 100 ft (30 m) wide were left along tributary streams which were flowing greater than 0.5 ft³/sec (14 l/sec); 300 ft (91 m) wide buffer strips were left along main streams.

Site:	**Rate of application**		**Date of application**	**Treatment area**		**Range Concentrations**		
	lb-N/ac	**kg-N/ha**				**NH_3**	**NO_3**	**Urea**
				ac	ha	mg/l		
Townsend Creek	200	224	Apr. 76	102	41			
Pre-treatment						0	0-0.05	0-0.02
Post-treatment						0-0.11	0-0.008	0-0.75
Big Quilcene River	200	224	Apr. 76	800	324			
Pre-treatment						0-0.03	0-0.06	0-0.01
Post-treatment						0-0.05	0-0.09	0-0.04

Table XI.B.10.—Stream water quality and quantity of flow following fertilization of a forested watershed, 1971: Fernow Experimental Forest, W.Va. (Aubertin and others 1973)

Treatment: Hardwood sprouts and seedlings were fertilized by helicopter with urea. No attempt was made to avoid a small perennial stream.

Site:	Rate of application		Date of appli-cation	Treatment area		Concentration			
						NH_4-N		NO_3-N	
	lb-N/ac	kg-N/ha				max	ave	max	ave
				ac	ha	-------------mg/l-------------			
Treated	230	258	May 71	74	30				
1970-1971						0.8	0.23	19.8	0.76
1971-1972							0.19		0.10
Control	---	---	---	---	---				
1970-1971							0.19		0.10
1971-1972							0.20		0.21

Table XI.8.11.—Stream water quality following fertilization of a gaged experimental watershed, spring 1970: South Umpqua Experimental Forest, Oreg. (Moore 1971)

Treatment: Watershed 2 was fertilized in March 1970 by helicopter. Urea, prill formulation, was applied and there was no attempt made to leave an untreated buffer zone along the stream. Watershed 4 was untreated and served as a control.

Site:	Rate of application		Date of appli-cation	Treatment area		Concentrations		
	lb-N/ac	kg-N/ha				Urea-N	NH_3-N	NO_3-N
				ac	ha	-------------mg/l-------------		
Watershed 2	200	224	Mar. 70	169	68	1.39	0.048	0.177
Watershed 4	---	---	---	120	49	0.006	0.005	0.002

Table XI.B.12.—The impact of forest fertilization on stream water quality in the Douglas-fir region—a summary of monitoring studies in Alaska, Idaho, Oregon, and Washington (Moore 1975a, 1977)

Treatment: Aerial application of urea.

Site:	Rate of application		Date of application	Treatment area		Peak Concentration					
						Urea-N		NH_3-N		NO_3-N	
	lb-N/ac	kg-N/ha		ac	ha	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post treatment
						mg/l					
Burns Creek[1]	50	56	Nov 1970	1390	562	0	0	0	0	0	0.068
Canyon Creek	200	224	Nov 1969	3325	1346	0.005	15.20	nd	nd	0.005	0.80
Coyote Creek	200	224	Mar 1970	170	68	0.006	1.39	0.005	0.048	0.002	0.177
Crabtree Creek	200	224	May 1969	570	230	---	24.00	0	0.080	0	0.25
Dollar Creek	200	224	Apr 1971	85	34	0.016	44.40	0.030	0.490	0.060	0.13
Elochoman Creek	200	224	Nov 1369	735	297	0.073	19.10	nd	nd	nd	4.00
Fairchilds Creek	200	224	Apr 1972	475	192	0.008	23.40	0.009	0.280	0.030	0.828
Falls Creek	190	213	May 1970	650	263	nd	nd	0.020	1.28	0.015	1.67
Jackson Creek	150	168	May 1969	235	95	0.007	0.09	0.004	0.044	0.065	0.116
Jimmycomelately Creek	200	224	Apr 1970	120	49	0.002	0.71	0	0.040	0.005	0.042
McCree Creek	50	56	Oct 1970	1265	513	0	0.62	0	0	0	0.210
Mica Creek	200	224	Sep 1972	115	47	0	0.30	0	0	0.15	0.28
Mill Creek	200	224	Dec 1969	565	228	0.02	0.68	0	0.12	0.02	1.32
Nelson Creek	200	224	Apr 1970	95	38	0.016	8.60	0.010	0.32	0.290	2.10
Newaukum Creek	150	168	Sep 1971	6085	2463	0.009	0.26	0	0.008	0.011	0.438
Pat Creek	200	224	Apr 1972	600	243	0.003	3.26	0.007	0.079	0.061	0.388
Quartz Creek	200	224	May 1972	125	51	0.004	1.75	0	trace	0.120	0.70
Roaring Creek	200	224	Mar 1972	660	267	0.007	0.76	0.004	0.040	0.017	0.210
Row Creek	150	168	Oct 1972	6500	2630	0.006	0.13	0.005	0.022	0.004	0.044
Skookumchuck Creek	150	168	Sep 1969	470	191	0	2.63	0.004	0.026	0.005	0.085
Spenser Creek	200	224	Nov 1972	7680	3108	0.019	0.37	0.041	0.123	0.005	0.005
Tahuya Creek	200	224	Oct 1972	4005	1620	0.01	27.20	0	1.40	0.01	1.83
Thrash Creek[2]	200	224	May 1974	300	121	---	---	nd	0.06	nd	1.88
Three Lakes Creek	190	213	May 1970	170	69	nd	nd	0.015	0.13	0.003	2.36
Trapper Creek	200	224	Apr 1970	160	64	0.008	0.70	0	0.010	0.034	0.121
Trout Creek	200	224	Mar 1968	1600	648	0.10	14.00	0.12	0.700	0.03	0.160
Turner Creek	200	224	Mar 1972	870	352	0.004	4.36	0	0.046	0.032	0.243
Waddel Creek	200	224	Dec 1969	1480	600	0.01	2.48	0	0.340	0.02	0.99
Wishbone Creek	200	224	May 1972	115	46	0	0.30	0	0	0.12	0.28

[1] $(NH_4)_2 SO_4$ applied

[2] NH_4NO_3 applied

nd = no data available or not determined

APPENDIX XI.C:

REFERENCE SOURCES FOR PESTICIDE CHEMICALS

Common name: 2,4-D

Chemical name: 2,4-dichlorophenoxyacetic acid

Other names: Stauffer, Esteron, Amine, Dacamine

Registered use: Control method for herbaceous and woody plants on cropland, forest, and rangeland, in orchards, on fallow land, and in pastures.

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Common name:	Dichlorprop, 2,4-DP
Chemical name:	2-(2,4-dichlorophenoxy) propionic acid
Other Names:	Weedone 2,4-DP, Weedone 170, Envert 170
Registered Use:	Brush control on non-agricultural lands

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Common name:	2,4,5-T
Chemical name:	(2,4,5-Trichlorophenoxy) acetic acid
Other names:	Esteron 245—PGBE ester; Ded-weed—Isooctylester; Brush/killer Lo Vol 4T—Isooctylester; Dinoxol—Butoxyethanol ester.
Registered use:	2,4,5-T is registered for control of woody and herbaceous plants; especially for brush control, selective conifer release, and control of woody plants in rangeland and pastures.

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Common name:	Atrazine
Chemical name:	2-chloro-4-ethylamino-6-isopropylamino-s-triazine
Other names:	AAtrex 80 W
Registered use:	Selective control of broadleaf and grassy weeds in conifer reforestation where it serves to increase seedling survival appreciably; also used in forest and Christmas tree plantations of Douglas-fir, grand fir, noble fir, white fir, lodgepole pine, ponderosa pine, and Scotch pine.

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Common name:	Carbaryl
Chemical name:	1-Naphthyl N-methyl carbamate
Other names:	Sevin, Sevin 4-Oil
Registered use:	Suppression of various insect outbreaks including the gypsy moth, cankerworm, saddled prominent and tent caterpillar, and the spruce budworm (eastern and western).

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Cape Cod, Massachusetts. Mass. Pestic. Board, Publ. 547. 75 p.

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Common name:	Chlorpyrifos
Chemical name:	0,0-diethyl-0-(3,5,6-trichloro-2-pyridyl) phosphorothioate
Other names:	Dursban, DOWCO 179, LORSBAN
Registered use:	Insect control.

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Common name: Dalapon
Chemical name: 2,2-dichloropropionic acid
Other names: Dowpon, Dowpon C, Dowpon M
Registered use: A moderately specific grass herbicide commonly used as a pre-plant treatment on conifer planting sites.

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Weed Science Society of America. 1974. Herbicide handbook of the Weed Science Society of America. 3rd ed. 430 p. Champaign, Ill.

Common name: Dicamba
Chemical name: 3,6-dichloro-o-anisic acid; also 2-methoxy-3,6-dichlorobenzoic acid
Other names: Banvel, Banvel Brush Killer, Banvel 5G Granules
Registered use: Brush control on noncroplands, including forest lands.

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Common name: Diflubenzuron
Chemical name: N(((4-Chorophenyl) amino)carbonyl)-2,6-di fluorobenzamide
Other names: Dimilin, Difluron, TH-6040
Registered use: Control of the gypsy moth; also used in aquatic ecosystems.

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Common name: Ethylene Dibromide
Chemical name: 1-2 dibromoethane
Other names: EDP, Fumo-gas, E-D-Bee, Bromo-fume, Soil-Fume, Dowfume, Urifume
Registered use: Forest insecticide against Douglas-fir beetle, Jeffrey pine beetle, mountain pine beetle, roundheaded pin beetle, spruce beetle, California flatheaded bores, Monterey pine ips, fir engraver beetle, and western pine beetle.

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White, V.L. 1972. Letter to Stanley I. Undi, U.S. Dep. Agric., For. Serv. from Great Lakes Chem. Corp. [Feb. 21, 1972.]

Common name: Fenitrothion
Chemical name: 0,0-dimethyl-0-(3 methyl-4-nitrophenyl) phosphorthioate; also 0,0-dimethyl 0-(4-nitro-m-tolyl) phosphorothioate (1)
Other names: Sumithion, Sumitomo
Registered use: Control of hepidoptera, diptera, orthoptera, hemiptera, and coleoptera in field crops and on fruits and vegetables; forest protection through control of Japanese pine sawyer, pine caterpillar, hemlocklooper, spruce budworm, bark beetle, and weevil; control of insects affecting public health such as mosquitos, flies, bedbugs, and cockroaches; and control of locust and grasshopper.

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Common name:	Malathion
Chemical name:	(0,0-dimethyl dithiophospate of diethylmercaptosuccinate)
Registered use:	Control of a number of forest insects including defoliators and sucking insects of conifers and hardwoods.

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Common name:	MSMA
Chemical name:	Monosodium methane arsonate or Monosodium acid methan arsonate
Other names:	Silvisar 550 Tree Killer, Vichem 120 Arsonate Silvicide, Glowon Tree Killer
Registered use:	For post-emergent weed control and as a silvicide for control of undersirable conifers and big leaf maple.

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Common name:	Orthene (acephate)
Chemical name:	(O,S,Dimethyl acetylphosphoramidothioate)
Registered use:	Control of gypsy moth.

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Common name:	Picloram
Chemical name:	4-amino-3,5,6-trichloropicolinic acid
Other names:	Tordon, ATCP
Registered use:	Control of annual and deep rooted perennial weeds in noncropland.

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Common name:	Silvex-fenoprop
Chemical name:	2-(2,4,5-trichlorophenoxy) propionic acid
Other names:	Kuron, Weedone
Registered use:	Control of woody plants, trees, and shrubs; specific brush control in forest site preparation and release; aquatic herbicide.

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Common name:	Simazine
Chemical name:	(2-chloro-4,6 bis(ethylcunino)-s-triazine)
Other names:	Princep 80W
Registered use:	Weed control in Christmas tree plantations.

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Common name:	Trichlorfon
Chemical name:	Dimethyl-(2,2,2-trichloro-1-hydroxy-ethyl) phosphorate
Other names:	Dylox
Registered use:	Control of the gypsy moth larvae on forest land shade trees.

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GLOSSARY

Below is a glossary of terms appearing in the text of this handbook. Those terms drawn from specific sources have been cited with a code in parentheses following the definition. Such citations are listed under "Sources" at the end of the Glossary (e.g., DGT stands for "Dictionary of Geological Terms"). Those terms with no citations have had a definition prepared for use in this handbook. Words not listed in the glossary can be found in standard sources.

Access road: Any road used to gain access to an area for the purpose of carrying out some form of management. These roads may be a temporary or permanent part of the transportation system.

Active flood plain: See Bankful stage.

Activity: Work processes conducted to produce, enhance, or maintain outputs or to achieve management and environmental quality objectives.

Acute toxicity: Brief and severe physical and/or psychological disturbances resulting from a single dose or exposure to a toxic or poisonous substance.

Advected energy [fluxes]: The process of energy transport by the atmosphere or water bodies from one location to another due to circulation of these bodies.

Aeration potential: (See Oxygen saturation level.)

Aerial drift: The movement of pesticide droplets or particles by wind and air currents from the target area to an area not intended to be treated. (PAST)

Aerial skidding: The process of hauling logs by sliding them off the ground along a cable. (SAF)

Aggradation: The raising of the surface of streambeds, floodplains, and the bottoms of other water bodies by the accretion of material eroded and transported from other areas. It is the opposite of degradation.

Aggraded stream: A stream that has built up its grade or slope by deposition of sediment. (DGT)

Ammonification: The biochemical process whereby ammoniacal nitrogen is released from nitrogen-containing organic compounds. (SSSA)

Ammonifying microorganisms: Microorganisms that are responsible for ammonification of nitrogen-containing organic material. (See Ammonification.)

Angle of internal friction (coefficient of friction): The angle at which the driving forces in a soil mass due to gravity are equal and opposite to the resisting forces due to friction; a measure of soil strength due to interlocking of individual soil particles.

Angular canopy density (ACD): A measure of the canopy density along the path of incoming solar radiation. It is measured using a gridded mirror tilted at an angle so that a person looking down on the mirror views the surrounding vegetative canopy in the same perspective as the incoming solar radiation. The number of grids covered by the canopy can be measured and converted to a percent canopy cover.

Animal skidding: The use of animals such as mules or horses to slide loads along the ground.

Antecedent moisture: The degree of wetness of a soil at the beginning of a runoff or storm period, expressed as an index or as the total volume of water stored in the soil. (WPG)

Antecedent rainfall: The rainfall or precipitation occurring during some period prior to the event of interest. This expression is intended to express watershed wetness. (VTC)

Aquatic environment: An environment in which all conditions, circumstances, and influences surrounding and affecting the development of an organism or groups of organisms pertain to water. (WPG)

Area-inches: A measure of volume. One inch of depth over the entire surface of a delineated piece of land.

Armor: (1) To apply rock, mulch, or vegetation to damaged areas to serve as protective covering. (2) To use rock, concrete, asphalt, gravel, riprap, gabions, or equivalent for protection of a ditch, channel, or low water crossing. (3) Any natural-occurring quality, characteristic, situation or thing that serves as a protective covering.

Aspect: The compass direction that the slope of the land faces toward (e.g., north, northwest, south), (WPG)

Balanced road construction: Cut-and-fill road design; material cut on the uphill side of a road is placed in fills on the downhill side.

Balloon logging: A system which employs balloons to transport timber from the stump to a collection point.

Bankful discharge: Discharge at a river cross section which just fills the channel to the tops of the bank, marking the condition of incipiant flooding.

Bankful stage: Water surface elevation of the active floodplain.

Bankful width: The width of the effective area of flow across a stream channel when flowing at bankful discharge.

Bare soil: Mineral soil without vegetative ground cover, rock, or litter on the soil surface.

Basal area: The area of the cross-section of a tree stem near its base, generally at breast height and inclusive of bark. Stand basal area is generally expressed as the total basal area per unit area. (SAF)

Baseline condition: Hydrologic state of a watershed where complete hydrologic utilization is achieved. (See Complete hydrologic utilization)

Bedding: A silvicultural process where soil is placed in long ridges approximately 6 inches high and 6 feet at the base to elevate tree roots above a high water table or to concentrate soil nutrients where they can be readily utilized.

Bedding planes: Planar or nearly planar surfaces that visibly separate each successive layer of stratified rock.

Bedload: Material moving on or near the stream bed by rolling, sliding and sometimes making brief excursions into the flow a few diameters above the bed. It is not synonymous with discharge of bed material.

Bedrock sink: Term used to denote when bottom bedrock is functioning as a heat sink within a flowing stream. (See Energy sink)

Bench: A working level or step in a cut which is made in several layers. A small terrace or comparatively level platform breaking the continuity of a slope. (DGT)

Best Management Practices (BMP): A practice or combination of practices that are determined (by a state or designated area-wide planning agency) through problem assessment, examination of alternative practices, and appropriate public participation to be the most effective, practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by non-point sources to a level compatible with water quality goals.

Biochemical oxygen demand (BOD): The amount of dissolved oxygen, generally expressed in parts per million, required by organisms for the aerobic biochemical decomposition of organic matter present in water. (WWU)

BMP: (See Best Management Practices.)

BOD: (See Biochemical oxygen demand.)

Braided stream: A stream flowing in several dividing and reuniting channels resembling the strands of a braid, the cause of the division being the obstruction by sediment deposited by the stream.

Broadcast burn: Allowing a controlled fire to burn over a designated area within well-defined boundaries for reduction of fuel hazard, as a silvicultural treatment or both. (SAF)

Bucking: To cut tree length logs into shorter lengths.

Buffer strip: (See Waterside area.)

Cable logging: Cable systems are designed to yard logs from the felling site by a machine equipped with multiple winches. Cable logging is highly efficient for logging steep rough ground on which tractors cannot operate. Cable systems could be classified as either high lead, skyline, or balloon. (CEAP)

Cable yarding: Operation of hauling logs to a collection point using a cable system. (See cable logging.)

Caloric deficit: The energy (calories) needed to bring a snowpack temperature up to an isothermal temperature of 0° C.

Canopy: The more or less continuous cover of branches and foliage formed collectively by the crowns of adjacent trees and other woody growth. (SAF)

Carbamate: A synthetic organic pesticide which contains carbon, hydrogen, nitrogen, and sulfur, and belongs to a group of chemicals which are salts or esters of carbonic acid. Carbamates may be fungicides, herbicides, or insecticides. Examples: aldicarb, carbaryl, carbofuran, and methomyl.

Cation exchange: The exchange of cations held by soil particles with other cations that are in the water solution surrounding the soil particles.

Cation exchange capacity (CEC): The sum total of exchangeable cations that a soil can absorb. Expressed in milliequivalents per 100 grams of soil or per gram of soil (or of other exchangers such as clay). (SCS, SSSA)

Channel bars: An alluvial deposit or bank of sand, gravel, or other material at the mouth of a stream or at any point in the stream itself which causes an obstruction to flow. (NIA)

Channel gradient change: A change in channel slope which can alter energy relationships that can, in turn, cause streambank and channel erosion or aggradation.

Channel interception: That portion of precipitation that falls directly into the channel or into open water channel extensions.

Channel stability: The relationship of sediment supply and stream energy available in a channel system. As changes occur in either supply or energy, the channel stability is affected and the channel tends to adjust its boundaries to accommodate the change, i.e., when the supply exceeds the carrying capacity (aggradation occurs) or the energy exceeds supply (degradation occurs).

Channel stability rating: A numerical rating of channel stability using Pfankuch's (1972) procedures which account for hydraulic forces, resistance of channel to flow forces, and the capacity of the stream to adjust and recover from changes in flow and/or sediment load.

Chemical-biological balance: Biological balance relating to the relationship of the earth's chemicals to plant and animal life (biogeochemical). (WPG)

Chip and spread: Converting wood to chips and scattering the resultant material. (SAF)

Chlorinated hydrocarbon: A synthetic organic pesticide that contains chlorine, carbon, and hydrogen; they are generally very persistent (compared to carbamates or organophosphates). Examples: DDT, endrin, lindane. Same as Organochlorine.

Chronic toxicity: Physical and/or psychological disturbances resulting from repeated doses or exposure of a poisonous or toxic substance over a period of time.

Claypan: A dense, compact layer in the subsoil having a much higher clay content than the overlying material, from which it is separated by a sharply defined boundary. (SSSA)

Clay stone: An indurated clay having the texture and composition, but lacking the fire lamination or platyness of shale.

Clearcutting: The harvesting in one cut of all trees on an area for the purpose of creating a new, even-aged stand. The area harvested may be a patch, stand, or strip large enough to be mapped or recorded as a separate age class.

Cohesion: The bonding of soil particles by thin water films, generally resulting in an increase in shear strength up to some minimum moisture content.

Cohesive soils: Soils that have relatively high shear strength when moist.

Colluvial debris (colluvium): A general term applied to loose and incoherent deposits, usually at the foot of a slope or cliff and brought there chiefly by gravity. Talus and cliff debris are included in such deposits. (DGT)

Compaction: The packing together of soil particles by instantaneous forces exerted at the soil surface resulting in an increase in soil density through a decrease in pore space.

Complete hydrologic utilization: Exists when the vegetation onsite is capable of utilizing water and energy at the maximum rate for the species and site.

Condition: Refers to a hydrologic state of a watershed, i.e., baseline, existing or proposed.

Cover density: An index which references the capability of the stand or cover to integrate and utilize the energy input to transpire water. It varies according to crown closure, vertical foliage distribution, species, season, and stocking.

Creep: (See Soil creep.)

Cribbing: A structure which can be made of metal, treated timber, or precast reinforced concrete, generally not watertight, used to contain unstable earth masses either above or below a road surface.

Critical temperature threshold: The temperature at which physiological effects on fish begin to be produced. The temperature threshold is an indicator of other water constituents such as dissolved oxygen.

Crop tree: Any tree forming or destined to form a part of the forest crop. Usually a tree selected in a young stand or plantation to be carried through to maturity. (SAF)

Cross drainage: A means, generally a culvert, of moving water from the uphill side of a road to the downhill side.

Crown closure: The percent of vegetation crown compared to open area as determined from an aerial photograph.

Cut-and-fill: Fill — the material added to reach the formation level. Cut — the excavation formed when the material is removed.

Cut banks: The concave wall of a meandering stream that is maintained as a steep or overhanging cliff by the impinging of water at its base. (See also Cut slope.) (DGT)

Cut slope: On sloping land, exposed banks above a road created by excavation during road construction.

Cutting block: Cutting area or felling area. An area on which trees have been, are being, or are to be cut. (SAF)

Cutting plan: Part of the silvicultural plan that describes the method of cutting (clearcut, seedtree, etc.).

Debris avalanche: Rapid, shallow mass movement on a hillslope involving soil, rock, and organic matter; less fluid in behavior than debris flow.

Debris dam: A dam in a channel resulting from the collection of tree limbs, logs, and other obstructions.

Debris flow: Rapid, shallow mass movement on a hillslope involving soil, rock, and organic matter; more fluid behavior than debris avalanche.

Debris in channel: Those obstructions in a stream channel as a result of silvicultural activities or natural events.

Debris jam: See Debris dam.

Debris slide: The slow-to-rapid downward movement of predominantly unconsolidated and incoherent earth and debris in which the mass does not show backward rotation but slides or rolls forward, forming an irregular hummocky deposit which may resemble morainal topography. (DGT)

Debris torrent: Rapid, turbulent movement of soil, alluvium, and organic matter down a stream channel.

Defoliant: A herbicide which causes the leaves of a plant to drop off.

Degradation: The general lowering of the surface of the land or stream by erosive processes, by the removal of material through erosion and transportation by flowing water. (DGT)

Denitrification: The biochemical reduction of nitrate and/or nitrite to molecular nitrogen or an oxide of nitrogen. Under some conditions, it results in a loss of nitrogen from the forest ecosystem.

Deposition: The mechanical or chemical processes through which sediments accumulate in a resting place.

Desiccant: A material used to draw moisture from or dry up a plant, plant part, or insect. Desiccants are used primarily for pre-harvest drying of actively growing plant tissues when seed or other plant parts are developed but only partially mature; or for drying of plants which normally do not shed their leaves, such as rice, corn, small grains, and cereals.

Detection limit: The level at which, with current technology, a water quality component can be detected with certainty.

Directional felling: Cutting trees so that they will fall in a predetermined direction for purposes such as increased logging efficiency, minimizing stand damage, and reduction in pollution impacts.

Ditch check: A small dam or structure in a road ditch to slow water velocity.

Ditch drain: Means of moving concentrated water from an inside road ditch to an outside area.

Drag(s): A frame, usually iron, for roughly leveling a relatively loose or soft surface. (SAF)

Dry fall: Deposition of solid particles from the atmosphere during nonprecipitation events.

Dry ravel: Downslope movement of sediment particles or small rock on steeper slopes without flowing water.

Duff: The matted, partly decomposed organic surface layer of forested soils. (SOIL)

Earthflow: Slow (rates of centimeters to meters per year), deep-seated (failure plain commonly 5-15 meters below surface) mass movement. (AGI)

Effective stream width: Length of shadow required to reach from one bank to the other; thereby effectively shading the stream.

Effective weight: Dry weight of soil minus the effect of buoyancy in the zone of saturation. (AGI)

Electrochemical exchange: Chemical action employing a current of electricity (lightning) to cause or to sustain a chemical reaction. (DMM)

Endline: To winch in without the use of block or pulleys to change the direction of pull.

Energy aspect: Refers to a combination of elevation and three aspect classes — (1) north, (2) south, and (3) east and west — used in determining energy inputs for generating snowmelt and evapotranspiration estimates.

Energy balance: An accounting of all energy inputs and outputs within some defined system.

Energy sink: A place where energy can be stored or absorbed for use at some other time or place.

Enrichment ratio: The concentration of nitrogen or phosphorus in the eroded material divided by its concentration in the soil proper. (PNE)

Erosion—The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. Detachment and movement of soil or rock by water, wind, ice, or gravity. (SSSA)

The following terms are used to describe different types of water erosion:

Accelerated erosion—Erosion much more rapid than normal, natural, geological erosion, primarily as a result of the influence of the activities of man or, in some cases, of animals. (SSSA)

Channel erosion: Erosion in which material is removed by water flowing in well-defined channels: erosion caused by channel flow.

Gully erosion: The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from from this narrow area to considerable depths ranging from 1 or 2 feet to as much as 75 to 100 feet. (SSSA)

Rill erosion: An erosion process in which numerous small channels of only a few inches in depth are formed; occurs mainly on recently cultivated soils. (SSSA)

Sheet erosion. The removal of a fairly uniform layer of soil from the land surface by runoff water. (SSSA)

Splash erosion: The spattering of small soil particles caused by the impact of raindrops on very wet soils. (SSSA)

Erosion hazard: The possibility of soil loss due to erosion processes.

Erosion response unit: A delineated homogenous area that will respond uniformly to forces which cause surface erosion.

ET: (See Evapotranspiration.)

Evapotranspiration (ET): The loss of water from a given area by both evaporation from soil and open water surfaces, and by transpiration from plants.

Excess water: Increases in available water resulting from evapotranspiration reduction from canopy removal. Excess water can also be caused by reduced infiltration rates into bare or compacted soil.

Exchange surface: Surface of soil particles that exhibit enhanced chemical activity, exchanging absorbed ions with ions present in the soil water.

Exfiltration: Water flowing from soil mantle back onto the soil surface from saturated soils due to bedrock constrictions, concentration in draws, excessive precipitation, etc.

Existing condition: The current hydrologic state of the watershed. It may be thought of as, but is not necessarily the same as a fully forested watershed with the trees capable of maximum evapotranspiration (ET) for the energy and water available.

Factor of safety: A measure of the stability of a soil or rock mass, ratio of material strength retarding motion to applied stress tending to cause motion.

Fault: Surface or zone of rock fracture along which there has been displacement. (AGI)

Felling: The act of cutting down a standing tree. (SAF)

Fertilization: The act of applying fertilizer.

Fertilizer: Any organic or inorganic material of natural or synthetic origin which is added to a soil to supply one or more elements essential to the growth of plants. (SSSA)

Field capacity index: The moisture content in the soil at one-tenth bar of soil-water pressure.

Fill slope: Man-made slope below a roadbed resulting from road construction where additional material is added to build up all or part of the road surface.

Filter strip: (See Waterside areas.)

Fireline: A term for any cleared strip used in fire control. More specifically, that portion of a control line from which flammable materials have been removed by scraping or digging down to the mineral soil. (SAF)

Flow duration curve: A graphical presentation of the percent of time streamflow equals or exceeds various levels of flow.

Fly logs: Logs carried completely off the ground during yarding.

Foliar drip: Loss of nitrogen from trees and understory to litter and organic layer on forest floor.

Ford: An unbridged stream crossing.

Forest cover density: An index representing the efficiency of a three-dimensional canopy system to respond to energy input.

Fracture: Any break in rock, whether or not displacement is involved.

Fragipan: A natural soil horizon with higher bulk density than the overlying horizons, seemingly cemented when dry but having a moderate to weak brittleness when wet. The layer is low in organic matter, mottled, slowly or very slowly permeable to water, and may show occasional or frequent bleached cracks which define polygons.

Free water: The water (liquid state) being held within a snowpack. This free water is generally considered to be less than 6 percent by volume for free-draining snow.

Free water surface: The surface of water bodies (i.e., streams, lakes, ponds, etc.).

Frictional resistance: Mechanical resistance to the relative motion of contiguous bodies or of a body and a medium.

Fuel break: A wide strip with a low amount of fuel in a brush or wooded area to serve as a line of fire defense and usually covered with grass to provide soil cover. (WPG)

Fuel management: The management and manipulation of fuels (vegetation) so as to lower fire hazard.

Fuel management plan: Part of the silvicultural plan that describes the type of fuel management to be used.

Full bench road: (See Full bench section.)

Full bench section: To construct a roadbed entirely on natural ground. Generally used on cross slopes 55 percent or greater.

Fungicide: An agent, such as a spray or dust, used for destroying fungi. (RHD)

Gabion: A specially designed basket or corrosion resistant wire boxes used to hold rock and other coarse aggregate. These wire boxes may be locked together to form sea walls, revetments, deflectors, and other structures. (WWU)

Glacio-lacustrine clays: Fine clay-size particles deposited in glacial lakes. Usually clay size but not clay minerals.

Gravitational stress: Acceleration of a mass due to gravity.

Ground cover: Any material (i.e., rock, litter, vegetation) which is attached to or lying on the soil surface.

Ground-lead cable yarding systems: A method of powered cable logging in which a main line is led out to the logs through a lead block fastened close to the ground level. Generally operated by a double-drum power unit carrying the main and haul-back lines. (SAF)

Gunite: (See Shotcrete.)

Hand pulpwooding: The procedure of driving trucks through the woods to felling sites and hand-loading wood cut primarily for manufacturing into wood pulp.

Hardpan: A hardened or cemented soil horizon or layer. The soil material may be cemented by iron oxide, silica, calcium carbonate, or other substances. The hardness does not change appreciably with changes in soil moisture content.

Harvesting: (See Timber harvesting.)

Hazard index: Indicates the intensity of analysis that may be necessary to adequately evaluate soil mass movement potential.

Headwall scarp: Steep (generally 50°) slope at the upslope end of a mass movement landform produced by the downslope movement of material away from the face. (AGI)

Heat flux: The quantity of heat transported during a given time period through a unit area that is perpendicular to the flow direction.

Heat sink: (See Energy sink.)

Helicopter logging: A system for hauling timber from stump to a collection point that employs a helicopter as the means of transportation. (CEAP)

Herbicide: A substance used to inhibit or destroy plant growth. If its effectiveness is restricted to a specific plant or type of plant, it is known as a selective herbicide. If its effectiveness covers a broad range of plants, it is considered to be a non-selective herbicide. (WPG)

Heterotrophic bacteria: Bacteria requiring complex organic compounds of nitrogen and carbon for metabolic synthesis.

High-lead logging: A method for transporting logs from the stumps to a collecting point by using a power cable, passing through a block fastened high off the ground, to lift the front end of the logs clear of the ground while dragging them. (CEAP, SAF)

High-lead yarding: The initial hauling to a collecting point in a high-lead logging system. (See High-lead logging.)

Hummocky topography: Irregular landscape of benches and depressions, indicative of mass movement activity.

Humus layer: The well-decomposed, more or less stable, part of the organic matter in mineral soil. (SOIL)

Hydrographic area: A small sub watershed of a first order watershed.

Hydrologic province: A subunit of a hydrologic region. Provinces are divided based on major climatic and hydrologic differences. (See Hydrologic regions.)

Hydrologic regimes: The climatic, lithologic, topographic, vegetation factors, and the temporal distribution of seasonally variable factors which determine the extent of stability between a stream and its drainage basin.

Hydrologic regions: Regions that have been delineated based upon major climatic and hydrologic differences.

Hydrologic utilization: The use of soil-water for biological growth and maintenance. Complete hydrologic utilization is equivalent to potential evapotranspiration.

Hydrolyzation: A chemical decomposition in which a compound undergoes a reaction with water resulting in new compounds or ions.

Ignition pattern: Distribution of many individual fires over an area simultaneously or in quick succession. (KPD)

Impacted areas: Uncut and cut areas of the watershed which are affected by a silvicultural prescription.

Immobilization: The chemical or physical binding of ions and compounds such that they are not chemically active or capable of going into solution.

Impaired drainage: Where subsurface water movement is obstructed by a relatively impermeable material, as at the failure plane of an earthflow. (AGI)

Incident heat load: The source of heat influx that causes water temperature to increase.

Incipient drainage depression: Linear depression orientated downslope that may carry surface runoff only during infrequent storms, commonly the site of debris avalanche-debris flow.

Incremental precipitation: The amount of precipitation falling over some specified interval of time.

Infiltration rate: A soil characteristic determining or describing the maximum rate at which water can enter the soil under specified conditions, including the presence of an excess of water. (SSSA)

Inorganic phosphorus: Phosphorus compounds that do not include carbon. Ionic forms are readily soluble in water.

Insecticide: A pesticide used to control insects.

Inside road ditch: A channel located adjacent to a road at the foot of the cut bank designed to concentrate water and reduce erosion on the road.

Insloped road: A road sloped (at 1 to 2 percent) toward the cut bank to facilitate the drainage of water off of the road surface.

Insoluble component: That portion of the nutrients entering a stream as relatively insoluble compounds or ions via surface flow either adsorbed to soil particles or as suspended solids.

Integral arch: An arch attached to the skidding machine to provide lift to the loading end of the log, and to improve the ease of backing up on rough steep terrain.

Interception loss: That portion of precipitation that is caught and retained on vegetation, litter layer or structures and subsequently evaporated without reaching the ground. (GOM)

Intracycle: A cycle (i.e., nutrient cycle) within the ecosystem. The forest nutrient cycle is generally segmented into three compartments: inputs, intracycle, and outputs.

Intracycle process: Biochemical processes taking place within an intracycle. (See Intracycle.)

Intragravel water: Water within the pore spaces of stream bottom gravel material.

Isothermal snowpack: A snowpack that has the same temperature throughout its vertical profile.

Jackpot burn: (See Spot burn.)

"Jack-strawed" trees: Patch of trees tipped in different directions, commonly indicative of mass movement activity. (AGI)

Jammer: A light weight 2-drum winch with a wooden spar, generally mounted on a vehicle which is used for both skidding and loading. (SAF)

Joint: Surface of actual or potential fracture or parting in a rock, without displacement.

Landslide: Sudden downslope movement of earth and rock.

Land system inventory: A seven level land inventory system which uses selected differentiating characteristics of soils, natural vegetation, and geology for identifying and delineating component parts of a landscape. The maps and associated legends produced at a given inventory level provide data for use at selected levels of land management.

Latent heat exchange: Energy given off or absorbed in a process (evaporation/condensation).

Leaf area index: Ratio of leaf surface area to projected ground surface area.

Leave strip: (See Waterside area.)

Limiting nutrient: An essential nutrient which is not available to timber in adequate amounts to insure normal growth (i.e., nitrogen, phosphorus, and potassium).

Linear depression: Incipient drainage depression.

Litter interception: That component of precipitation that is intercepted by the litter layer and eventually evaporated back to the atmosphere.

Litter layer: The surface layer of the forest floor consisting of freshly fallen leaves, needles, twigs, stems, bark, and fruits. (SAF)

Logging plan: Part of the silvicultural plan that includes a planimetric map which depicts the type of logging system, landings, and road plan to be used.

Log landing: Any place where round timber is assembled for further transport, commonly with a change of transport method. (SAF)

Lop and scatter: To chop branches, tops, and small trees after felling and then spread the resulting materials more or less evenly over the ground without burning. (SAF)

Lopping: Cutting off one or more branches of a tree, whether standing, felled, or fallen. (SAF)

Machine pile (and burn): Slash which is put in piles by machinery to subsequently be burned.

Manning's equation: An empirical formula used to calculate the velocity of flow based on channel roughness, the hydraulic radius, and the slope of the energy gradient line.

Mass failure: (See Mass wasting.)

Mass movement: Unit movement of a portion of the land surface as in creep, landslide, or slip.

Mass wasting: A general term for a variety of processes by which large masses of earth materials are moved by gravity either slowly or quickly from one place to another.

Masticate: Chewing or grinding wood into small pieces.

Mechanized logging operations: The use of self-propelled ground equipment to fall and bunch and/or limb and buck or top a tree.

Melt threshold temperature: An index temperature relating to when the snowpack will begin to melt.

Microrelief: Small-scale, local differences in topography that are only a few feet in diameter and have elevational differences of a few inches to 6 feet. (SSSA)

Mineral soil: A soil consisting predominantly of, and having its properties determined predominantly by, mineral matter. Usually contains less than 20 percent organic matter, but may contain an organic surface layer up to 30 cm thick. (SSSA)

Mineralization: The release of mineral matter from organic matter as a result of microbial decomposition.

Mitigative controls: The physical, chemical, or vegetative measures applied to ameliorate existing problems.

Modified Soil Loss Equation (MSLE): The Universal Soil Loss Equation (USLE) as it has been revised for application to forest conditions.

Mohr-Coulomb Theory of earth failure: States that failure in a material occurs if the shear stress on any plane equals the shear strength of the material. (AGI)

Montmorillonite: (See Smectite.)

Mudflow: Rapidly flowing mass of predominantly fine-grained earth materials possessing a high degree of fluidity during movement.

Mulch: (1) Any material such as straw, sawdust, leaves, etc., that is spread upon the surface of the soil to protect the soil and plant roots from effects of raindrops, soil crusting, freezing, evaporation, etc. (SSSA) (2) Any loose covering on the surface on the soil, whether natural, — like litter, or deliberately applied like straw, grass, or foliage, or artificial material such as cellophane. Used to conserve moisture, check weed growth, and protect from climate. (SAF)

Natural event: Event that takes place according to the laws of nature — inherent — not induced or changed by man's activities.

Nitrification: Biological oxidation of ammonium to nitrate or a biologically induced increase in the oxidation state of nitrogen.

Nitrogen fixation: Biological conversion of elemental nitrogen (N_2) to organic combinations or to forms utilizable in biological processes. (SSSA)

Nitrosomonas: A soil bacteria that obtains energy for growth by oxidizing ammonia to nitrites.

Non-cohesive soil: Soil with a relatively low shear strength.

Non-point sources: For silviculture, sources from which the pollutants discharged are: (1) induced by natural processes, including precipitation, seepage, percolation, and runoff; (2) not traceable to any discrete or identifiable facility; and (3) are better controlled through the utilization of Best Management Practices, including process and planning techniques. (EPA) Nonpoint sources as used in this document includes natural pollution sources not directly or indireclty caused by man.

Normalized hydrograph: Representative hydrograph expressed as the percentage of annual flow which can or will occur during any 6-day interval.

Nutrient availability: The state in which nutrients must be to be available to plants.

Onsite: The specific area on which an event, occurrence, or activity has taken or will take place.

Onsite chemical balance changes: Silvicultural activity can result in release of chemicals which, in turn, may leach or wash into streams, thereby affecting nutrient and Biochemical Oxygen Demand (BOD) levels in water.

Open water: (See Free water surface.)

Organic phosphate: Phosphorus compounds that include carbon. They are not generally found as water soluble ions.

Organophosphate: A synthetic organic pesticide which contains carbon, hydrogen, and phosphorous. It acts by inhibiting a blood chemical called "Cholinesterase." As a rule, organophosphates are less persistent than the chlorinated hydrocarbon family. Examples: malathion and parathion.

Outslope construction: Used in construction to spread both the material and the potential flow of water out over a very large front with a subsequent low energy per unit for transport.

Overland flow (sheet flow): Runoff water which flows over the ground surface as a thin layer and does not infiltrate prior to reaching a stream, as opposed to the channelized (concentrated) runoff which occurs in rills and gullies. (WPG)

Overload stream: An aggraded stream, one with an excess of sediment supply as evidenced in a braided stream.

Overstory: That portion of trees in a forest forming the uppermost canopy layer.

Oxygen saturation levels: The maximum amount of oxygen that theoretically can be dissolved within water for the given temperature and elevation.

Patch cut: A modification of clearcutting. A 40- to 200-acre area cut as single settings, separated for a long as practicable, preferably until the regeneration is adequately shading the forest floor. (SAF)

Permeability class: An arbitrary classification of soil permeability into classes (i.e., very slow, slow, slow to moderate, moderate, etc.) Used in determining the soil erodibility factor (K) of the Modified Soil Loss Equation.

Pesticide: A chemical substance, compound, or other agent used to control, destroy, or prevent damage by a pest.

Phreatophyte: A plant that habitually obtains its water supply from the zone of saturation, either directly or through the capillary fringe. (DMM)

Piezometric surface: An imaginary surface representing the static head of groundwater and defined by the level to which water will rise in a well.

Piping (soil piping): Subsurface erosion that causes the formation of tunnel-like cavities.

"Pistol-butted" trees: Trees with a "J" shaped base with the stem displaced downslope, due to mass movement, snow creep, and other processes.

Planar failures: Shallow soil mass movement with a nearly flat plane of failure.

Plant growth regulator: A substance or organism that increases, decreases, or in some way changes the normal growth or reproduction of a plant.

Plow layer: A surface soil layer that has been mixed by human activities to an extent that the original properties of the soil have been modified.

Point bars: Sediment deposited on the inside of a growing meander loop. (DGT)

Pollution: The manmade or man-induced alteration of the chemical, physical, biological and radiological integrity of water. (Section 502, Pl 95-217 clean Water Act)

Pool areas: A body of water or portion of a stream that is deep and quiet relative to the main current. (NIA)

Pore space: The volume of the various pores in a soil. The space not occupied by solid particles.

Pore water pressure: The stress transmitted through the fluid that fills the voids between particles of a soil or rock mass.

Prescribed fire (prescribed burn): Skillful application of fire to natural fuels under conditions of weather, fuel moisture, soil moisture, etc., that will allow confinement of the fire to a predetermined area and at the same time will produce the intensity of heat and rate of spread to accomplish certain planned benefits. (KPD)

Prescribed underburning: Skillful application of fire used to reduce fuels under stands following logging to reduce fuels created by some cultural treatments; to kill unwanted trees and shrubs and/or reduce fuels from leaf and needle fall; and to control certain tree diseases. It is successful only with fire-resistant tree species and low to moderate fuel loadings.

Preventive controls: Those controls that apply to the pre-implementation, planning phase of a silvicultural activity.

Probit: a statistical unit of measurement of probability based on deviations from the means of a normal frequency distribution.

Proctor curves: Curves resulting from the standard Proctor compaction test showing the variation of optimum soil-water content related to maximum density. (EM)

Proposed condition: The hydrologic state of a watershed following a proposed silvicultural activity. It is synonymous with the "post-silvicultural" activity condition.

Procedural controls: Those controls that are concerned with administrative actions of a silvicultural activity.

Raindrop splash erosion: (See Erosion.)

Reaeration: The replenishment of deficit oxygen concentration in water.

Reflectivity: The fraction of radiation that is reflected back to the sky by the snowpack. A term used in energy budget modeling.

Release: Freeing a tree, or group of trees, from more immediate competition by cutting, or otherwise eliminating, growth that is overtopping or closely surrounding them. (SAF).

Residual soil: Soil developed in situ from underlying parent material.

Resource impacts: Change to the resource that alters natural processes.

Restricted drainage: Where subsurface water movement is obstructed by a relatively impermeable material, as at the failure plane of an earthflow.

Retaining structure: Structure which retains or restrains an oversteepened slope.

Rheological flow: A more or less viscous liquid flow of solid material.

Riffle: A shallow rapids in an open stream where the water surface is broken into waves by obstructions wholly or partly submerged. (NIA)

Ripping: (See Soil ripping.)

Riprap: A foundation or sustaining wall of stones put together without order on an embankment slope or water course to prevent erosion.

Rodenticide: A pesticide used to control rodents.

Rolling chopper: A cylindrical roller or water-filled drum equipped with several full-length cutting blades. Its purpose is to crush and cut brush and slash into small lengths.

Rolling dip: (1) To conform a road to the landscape by following the natural grade changes. (2) Used when constructing a road on nearly level terrain to provide for drainage by making small changes in grade.

Rotational failure: Mass movement with concave failure plane.

Sag pond: Poorly drained depression formed by rotational mass movement.

Salvage cut: The harvesting of trees that are dead, dying, or deteriorating (e.g., because overmature or materially damaged by fire, wind, insects, or other injurious agents) before the timber becomes worthless.

Saturated hydraulic conductivity: A measure of the rate of water traversing a unit area of soil in unit time per unit hydraulic gradient with the soil in a saturated condition.

Scalping: Paring off low and surface vegetation together with most of its roots to expose a vegetation-free soil surface, generally preparatory to sowing or planting. (CEAP)

Scarification: Loosening the topsoil or breaking up the forest floor to expose mineral soil.

Scour: Removal of loose material by running water, from the wetted portion of a stream channel.

Sediment: (1) Particles derived from rocks or biological materials that have been transported by a fluid. (2) Solid material (sludges) suspended in or settled from water.

Sediment delivery index: An estimated fraction of the total potential soil loss from a disturbed site that may be moved over land and deposited in a stream channel.

Sediment delivery ratio: The volume of sediment material actually delivered to a point in a watershed divided by the total amount of material available for delivery.

Sediment discharge (yield): The average quantity of sediment, mass or volume, but usually mass, passing a section in a unit time. The term may be qualified as, for example, suspended-sediment discharge, bedload discharge, or total sediment discharge.

Sediment rating curve: A graphical representation of the existing relationship between sediment concentration in mg/l and stream discharge in cfs.

Sediment supply: The amount of inorganic sediment made available in the channel for transport as either suspended or bedload sediment. Sources of sediment include contributions from surface erosion and soil mass movement, and that derived from the channel itself.

Sediment transport: Term used to discuss the movement of sediment within a stream channel system.

Sediment trap: Usually a small depression to capture sediment coming from on-going construction. A temporary measure to trap sediment.

Suspended sediment: In the process by which running water transports material, smaller particles are lifted far from the bottom and are sustained for long periods before being distributed through the whole body of the current. This constitutes the suspended load or that component called suspended sediment. (DGT)

Seed tree cutting: Removing trees in a mature stand so as to effect permanent openings of their canopies. This provides conditions for securing regeneration from the seed of trees retained for that purpose.

Selection cutting: A method of logging which removes trees from all size classes in an uneven-aged stand to maintain proper stocking as increments of trees move from younger to older classes.

Serpentine: A mineral of the serpentine group, such as antigorite and chrysotile. These minerals are prone to mass erosion. (DGT)

Shale: Fine-grained indurated detrital sedimentary rock formed by consolidation of clay, silt, or mud, and characterized by finely stratified structure.

Shear strength: The internal resistance of a body to shear stress.

Shear stress: That component of stress which acts tangential to a plane through any given point on a body.

Sheet flow: Surface runoff which flows over the ground in a thin layer as contrasted with runoff that is concentrated in rills and gullies.

Shelterwood cutting: A method of harvest cutting involving two or three separate cuttings. The last cutting removes the shelterwood after adequate regeneration, encouraged by prior cuttings, has become established.

Shotcrete (also known as gunite): A mixture of cement, sand, or crushed slag and water sprayed over exposed soil on hillslopes to protect against surface erosion.

Siltstone: Indurated silt having the texture and composition, but lacking the fine lamination of shale.

Silviculture: The science and art of cultivating forest crops, based on a knowledge of silvics, which is the study of the life history and general characteristics of forest trees and stands with particular reference to locality factors, as a basis for the practice of silviculture (SAF).

Silvicultural activity: Activity associated with the care and cultivation of forest trees. It includes harvesting, regeneration systems, access systems, and various cultural practices (site preparation and timber stand improvement) that are appropriate to various management objectives.

Silvicultural plan: A plan outlining a proposed silvicultural activity, which should include methods of cutting, felling, yarding, fuel management, site preparation, miscellaneous cultural activities, and road and access system plans.

Silvicultural state: The status of the vegetation complex on units of land to which a silvicultural prescription has been applied. A silvicultural system or treatment actually applied to a unit or a description of the vegetative cover on all or a part of the unit. The state may be described as clear cut, thinned, forested, open, etc.

Silvicultural prescription: The management alternatives applied to a watershed or watershed subunit. The delineation of a watershed into a single unit or series of subunits to which the prescription is to be applied, is based on uniformity of soil depth, vegetation, precipitation, aspect, and other unique site factors. A uniform practice over the entire unit or several practices resulting in more than one silvicultural state per silvicultural prescription; i.e., the prescription may consist of patch cutting, thinning, and leaving part of the area uncut. The silvicultural prescription includes for each unit that part of the silvicultural plan that affects the evapotranspiration status of the vegetation.

Simulation: A technique for analyzing complex inter-relationships among variables based upon known or assumed influence of one variable on another. Often referred to as modeling, simulation provides a means of estimating and comparing the effects that a change in one or more of the variables will have on the other variables.

Site preparation: Preparing a site for the regeneration or planting of trees.

Site preparation plan: Part of the silvicultural plan that describes site preparation techniques to be used.

Site productivity: The present capability of a site for producing a specified plant or sequence of plants under a defined set of management practices.

Skidding (timber transport): A term for hauling loads by sliding from stump to roadside. The timber may slide more or less wholly along the ground (ground skidding) with its forward end supported (high lead skidding) or wholly off the ground — sliding along a cable — during its main transit (aerial skidding). (SAF)

Skid road (skid trail): Any path, more or less prepared, over which logs are dragged. (SAF)

Skyline cable system: A cable logging system which employs a heavy cable stretched between two supports upon which traverses a carriage to support at least the leading end of the log. (SAF)

Skyline logging: A method for transporting logs from stumps to collecting points that uses a heavy cable stretched between high points (such as in tall trees braced with guy lines) to function as an overhead track for a load carrying carriage. Logs are lifted up by cables or other similar devices, and powered cables are used to move the load back and forth along the main cable. (CEAP)

Slope configuration change: Alteration of the land slope, such as occurs in roadbuilding when cuts and fills are constructed.

Slope gradient: The amount of inclination from horizontal of a piece of land. Gradient is expressed in degrees or percent (tangent of the slope angle which is the amount of rise divided by the horizontal distance).

Slump: A slip resulting from the downward and backward rotation of a soil block or group of blocks with small lateral displacement. Closely related to earthflow in terms of their occurrence and genetic process. (DGT)

Smectite clay: Group of expanding lattice clay minerals. (AGI).

Snowpack ripening: The process of coarse crystal formation with an increase of the liquid phase within the snowpack. (VTC)

Snow redistribution: The change in the distribution of snow attributable to land management activities (i.e., increasing deposition in openings within forested areas).

Snow retention coefficient: A coefficient used in assessing snowpack redistribution associated with timber harvesting. The coefficient is the ratio of expected accumulation divided by the baseline or pre-harvest accumulation.

Soil creep: Slow, gradual, more or less continuous permanent deformation of soil under gravitational body stress.

Soil mass movement: Movement of soil material en masse under gravitational body stress.

Soil resource inventory: Term used by U.S. Forest Service for the systematic examination of soils in the field and laboratory, including descriptions, classifications, and mapping of soils and management interpretations according to their productivity and behavior under use. (See Soil survey.)

Soil ripping: Act of breaking up hard gravel, soft rock, tearing out stumps and boulders.

Soil survey: The systematic examination, description, classification, and mapping of soils in an area. Soil surveys are classified according to the kind and intensity of field examination. (SSSA)

Soil texture: The relative proportions of the various soil separates [sand, silt, and clay] in a soil as described by the classes of soil texture. (SCS, SSSA)

Solar ephemeris: A table showing the positions of the sun on a number of dates in a regular sequence. (RHD)

Solar loading: The flux of solar energy reaching the forest floor or water body of interest.

Soluble component: That portion of the nutrients that enters a stream as soluble ions via surface or subsurface flow.

Spot burn (jackpot): A method of burning where scattered concentrations of slash or other fuels are reduced by burning in place under fuel moisture and weather conditions which maintain low flame lengths and fire intensities.

Stability threshold: The maximum change that a stream reach can withstand and still maintain it's morphological characteristics due to either sediment supply and/or stream energy changes where channel adjustments will be initiated to accommodate these changes over time.

Stage felling: To fell timber and remove it in stages so as to reduce breakage, normally small timber first.

Stations (engineering): A unit of measure equivalent to 100 horizontal linear feet.

Stiff diagram: A method of plotting several variables using vectors on a graph, so that the combined effects of the variables are shown as an irregular polygon with a particular area.

Stream aeration: The process of air being mixed with and re-entering the stream water. This process can be observed visually as white or foaming water.

Stream channel encroachment: Encroachment occurs when bankful discharge width of a stream is reduced due to direct alterations such as bridges, roadfills, culverts, organic debris, etc.

Stream equilibrium: The balance of the availability of sediment supply based on the erosional rates of adjacent slopes, the stream system, and the energy available to transport this erosional debris in such a manner that the morphological characteristics of the stream channel are maintained.

Stream gradient: (See Water surface slope.)

Stream order: A method of numbering streams as part of a drainage basin network. The smallest unbranched mapped tributary is called first order, the stream receiving the tributary is called second order, and so on.

Stream power: Numerical expression of stream energy utilized in determining bedload transport rate which is the product of water surface slope, stream discharge, and a unit force factor of 62.4 lbs/ft^3-width of stream.

Stream productivity: The amount of living matter actually produced within the stream under investigation.

Stream shading changes: Changes that occur when trees and/or understory vegetation that contribute to the shading of water in streams are removed.

Streamside areas: (See Waterside area.)

Streamside management zone: (See Waterside area.)

Strip cutting: Removal of the crop in strips in one or more operations, generally for encouraging regeneration. (SAF)

Stripping: Clearing or removing ground cover.

Structure index: An index of soil structure (granular, blockly, massive, etc.) used in determining the erodibility (K) factor of the Universal or Modified Soil Loss Equation.

Subsurface flow: That part of the runoff that percolates through the soil mantle primarily under the influence of gravity before emerging as streamflow.

Surface erosion: (See Erosion).

Swelling clays: Expanding lattice clays which increase in volume when water moves into the crystal structure and decrease in volume when water is removed.

Swing operation: Moving logs to a landing from a distant deck to which they have been yarded. (CLS)

Symbiosis: The living together of two different organisms with a resulting mutual benefit. A common example includes the association of rhizomes with legumes. The resulting nitrogen fixation is sometimes called symbiotic nitrogen fixation. (See Nitrogen fixation).

Temporary road: A timber access road which is closed to traffic between timber needs. When closed the road is barriered, scarified, and reseeded to grass and forbs.

Tension cracks: Fissures in the earth formed by differential displacement between two blocks of earth caused by tensional stresses.

Terracing: Use of terraces (raised levels with sloped front or sides) in site preparation.

Thermal pollution: Disruption of the aquatic environment or other beneficial use due to heating of a stream or other water body.

Throughfall: The part of rainfall that reaches the ground directly through the vegetative canopy, as drip from leaves, twigs, and stems. (VTC)

Timber harvesting: A general term for the removal of physically mature trees in contrast to cuttings that remove immature trees. (SAF)

Timber stand improvement: A loose term comprising all intermediate cuttings made to improve the composition, constitution, condition, and increment of a timber stand. (SAF)

Topographic shading: Shading of streams, water bodies, or other areas of interest by topographic features positioned between the sun and area of interest, thereby eliminating direct solar radiation.

Toxicity: Quality, relative degree, or specific degree of being toxic or poisonous to an organism; the ability of a substance or chemical to produce injury. (RHD)

Tractor logging: Any system of logging in which a tractor furnished the motive power, whether by direct hauling or by skidding. (SAF)

Tractor skidding: Hauling logs by sliding using a tractor as the motive power. (SAF)

Translational movement: Downslope movement of a mass of soil and/or rock on a surface roughly parallel to the general ground surface.

Translocation of chemicals: The movement of a chemical within a plant or animal after it has entered by some path.

Transmissivity of solar radiation: Ability of solar radiation to pass through the forest canopy to the forest floor, snow pack surface or water surface.

Transport capability: In general terms, the integration of several variables which influence the ability of the stream to transport the sediment made available. The variables include velocity, gradient, bed roughness, existing sediment load, and particle size of material being transported.

Transportation plan: A plan that coordinates the transportation system for relatively large areas delineated by very limiting topographic features, economic centers, and legislative constraints. It provides the interface for the logging road system and the public road system.

Transportation system: The transportation network including all existing and planned roads, skid trails, bridges, airfields, and other transport facilities wholly or partly within or adjacent to the watershed area for silvicultural activities. (WPG)

Trash rack: A screen of parallel bars or mesh placed across a stream or turbine intake to intercept floating debris. (DMM)

Treated seed: Seeds that are chemically treated with a pesticide or fertilizer.

Understory: The woody species growing under a more or less continuous cover of branches and foliage formed collectively by the upper portions of adjacent woody growth. (WPG)

Uneven-aged stands: Stands with trees that differ markedly in age.

Unimpacted areas: Those unharvested zones of a watershed which are unaffected by a silvicultural prescription.

Universal Soil Loss Equation: An equation used for evaluating potential soil loss in specific situations. A = RKLSPC wherein A = average annual soil loss in tons/acre/year, R = rainfall factor, K = soil erodibility factor, L = length of slope, S = slope gradient, P = conservation practice factor, and C = cropping and management factor. (WPG)

Variable source area: The portion of the watershed that actively contributes to runoff. These areas are dynamic and vary with antecedent soil moisture, storm size and duration.

Vegetative change: Changes which include the removal of vegetative ground cover, canopy cover, or a change in vegetative type.

Vegetative cover: The vegetation that is effective in protecting the ground surface. May be composed of overstory and understory vegetation.

Vegetative ground cover: The effective vegetation and organic matter that is protecting the soil; this cover includes litter.

Vegetative shading: Shading of streams, water bodies, or other areas of interest by vegetation positioned between the sun and area of interest thereby reducing the direct solar radiation striking a surface.

Volatilization: The evaporation or changing of a substance from liquid to vapor. (SOIL)

Volcanic flow rock: Extrusive igneous rock — generally the result of a lava flow.

Volcaniclastic: Fragmental rock of volcanic origin; may be a lava flow breccis, ash flow breccia, air fall ash, mud flow (lahar) breccia, or other material.

Washload: That portion of the suspended load which is 0.062 mm or smaller (silts and clays).

Washoff: The flushing of chemicals deposited as dryfall or introduced chemicals from the foliage during precipitation events.

Water balance: A measure of continuity of flow of water. It is an accounting of all the inputs and outputs of the hydrologic system. (VTC)

Water bar: A ridge or mound made across a road or cleared strip to divert water to one side. (CEAP)

Water concentration: The condition that results when water is intercepted and allowed to converge instead of infiltrating into the soil or spreading naturally.

Water quality objective: A quantified statement that defines the quality of the water resource for a specific stream or stream segment. It is related to the uses of the water resources and may be in terms of existing water quality standards or other quantifiable conditions relating to water quality such as degree of channel aggradation or degradation.

Water quality standard: Quantitative or qualitative criteria for chemical, physical, and biological characteristics that are established for the purpose of providing water that is suitable for specific uses.

Water resource goal: A broad but concise statement of the desired state or condition for the water resource.

Water surface slope: The slope or gradient of the stream energy grade line. For open channels, it is measured as the slope of the water surface and is frequently considered parallel to the stream bed.

Waterside area: Land area of varying size and shape immediately adjacent to stream courses or to water bodies on which the type and/or intensity of land use is tempered to meet defined water resource goals. Terms such as streamside management zone, aquatic habitat zone, water influence zone, floodplain, buffer strip, and leave or filter strip are often used when referring to management direction for waterside areas.

Water yield: The runoff from a watershed, including ground water outflow. Water yield is the precipitation less the evapotranspiration losses and change in storage.

Water yield increases: Increases in water yield resulting from reduction in other components of the hydrologic balance — primarily evapotranspiration.

Weak link: A reference to the channel reach that is the most unstable either from an increase in streamflow and/or increase in sediment supply. Many such weak links are in a disequilibrium condition.

Winching: To hoist or pull with as if with a winch.

Windbreak: A planting of trees, shrubs, or other vegetation, usually perpendicular or nearly so to the principal wind direction, to protect soil, crops, homesteads, roads, etc., against the effects of winds such as wind erosion and the drifting of soil and snow. (SSSA)

Yarding: The operation of the initial hauling of timber from stump to a collecting point. Pulling logs from the tree stump to the skidway, landing, or (in rare cases) the mill.

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